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An Ecological Risk Assessment Framework (ERAF) for Ecosystem-based Oceans Management in the Pacific Region

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

This paper outlines an ecological risk assessment framework (ERAF) to support Ecosystem-Based Management (EBM) efforts in the Pacific Region in both the Pacific North Coast Integrated Management Area (PNCIMA) and Marine Protected Areas (MPAs). A systematic, science-based and defensible risk-based decision making structure is needed to help guide the transition from high-level aspirational principles and goals to more tangible and pragmatic objectives, strategies and actions that could be implemented in these areas. We emphasize that this framework builds upon methodologies from existing ecological risk assessment frameworks and processes, including the Australian Ecological Risk Assessment for the Effects of Fishing (ERAEF) and risk frameworks developed for other DFO Large Ocean Management Areas (LOMAs) amongst others. Adapting methodology from these processes has allowed the creation of an ERAF more specifically tailored to the goals and purposes of EBM in the Pacific Region. We describe the methodology and structure of the ERAF, which involves a scoping phase; followed by three increasingly quantitative levels of risk assessment, and discuss how this framework could be used to inform management activities. The ERAF provides methods for calculating risk of harm to an ecosystem from both single and multiple stressors, but more importantly it describes the steps necessary to provide transparent and defensible science-based advice on anthropogenic impacts for ecosystem-based management.

Cadre d'évaluation du risque écologique pour la gestion écosystémique des océans dans la région du Pacifique

RÉSUMÉ

Le présent document présente un cadre d'évaluation du risque écologique pour soutenir les mesures de gestion écosystémique dans la région du Pacifique; il s'applique à la zone de gestion intégrée de la côte nord du Pacifique (ZGICNP) et aux aires marines protégées. Il est nécessaire d'établir une structure décisionnelle justifiable, systématique et fondée sur la science et les risques afin d'appuyer la transition des principes et des objectifs idéaux de haut niveau vers l'application de stratégies, de mesures et d'objectifs plus tangibles et pragmatiques dans ces zones. Nous insistons sur le fait que ce cadre s'appuie les processus et méthodes d'autres cadres d'évaluation en place, notamment l'évaluation du gouvernement australien sur les risques écologiques et leurs effets sur la pêche et les cadres de gestion des risques élaborés pour d'autres zones étendues de gestion des océans (ZEGO) du MPO. Cet ajustement méthodologique a permis la création d'un cadre d'évaluation du risque écologique adapté aux objectifs propres à la gestion écosystémique dans la Région du Pacifique. Ce document décrit la méthode et la structure du cadre d'évaluation du risque écologique, qui comprend une phase d'établissement de la portée et une évaluation quantitative du risque à trois niveaux, suivies d'une discussion sur la façon dont le présent cadre pourrait être utilisé pour orienter les activités de gestion. Le cadre d'évaluation du risque écologique fournit des méthodes pour calculer le risque de causer des dommages à un écosystème que posent un ou différents agents de stress, mais avant tout, il décrit les étapes qu'il faut suivre pour fournir un avis scientifique transparent et probant sur les impacts d'origine anthropique à l'appui de la gestion écosystémique.

1 INTRODUCTION

The establishment of the Pacific North Coast Integrated Management Area (PNCIMA) and Pacific Region Marine Protected Areas (MPAs) presents a broad range of Ecosystem-Based Oceans Management challenges and opportunities. One of the main challenges associated with implementing ecosystem-based management is determining the linkages between specific human activities, their associated stressors, and valued ecosystem components (VECs) in a way that enables managers to prioritize among issues (Samhouri et al. 2012). A key step in addressing these challenges is the development of an ecological risk assessment framework (ERAF) founded on the best available science that: (i) identifies and ranks the risks of harm to ecosystem components from anthropogenic stressors, and (ii) informs the development of specific conservation objectives and management strategies to address these risks.

Management principles and goals have been drafted for the PNCIMA and many MPA initiatives in the Pacific Region. However, a systematic, science-based and defensible risk-based decision-making structure will help guide the transition from the high-level aspirational principles and goals to more tangible and pragmatic objectives, strategies and actions that could be implemented in PNCIMA, MPA initiatives and at regional scale management areas in the Pacific Region.

Recently a risk-based approach was proposed to identify indicators in order to monitor the achievement of Pacific region MPA conservation objectives (Davies et al. 2011). Here, we build on this approach and extend its scope to the larger scale PNCIMA, creating a structured approach to assess the potential risk of harm to ecosystem components from human activities (and their associated stressors) in this larger management area. The goal of developing this ecological risk assessment framework (ERAF) is to provide managers with science advice on the ecological risk consequences of anthropogenic stressors on ecosystem components, together with the processes and tools that can be used in the development of conservation objectives and management measures in PNCIMA and MPA initiatives in Pacific Region. This advice could also be valuable to inform other risk-based approaches applied within the Pacific Region (e.g. DFO Habitat Ecosystem Risk Assessment Framework, DFO's Sustainable Fisheries Framework).

The key elements of the ERAF described in this paper are:

1. Scoping:
    - Identification of the key features or properties of the system (VECs), including species, habitats and community/ecosystem properties;
    - Identification of the activities and stressors that have the potential to affect these VECs using pathways of effects models (POE s); and,
2. Risk assessment:
    - Assessing the risks of harm to each VEC from each activity and associated stressors singularly and cumulatively using appropriate criteria and scoring methodology.

By providing a systematic and transparent process for gathering, evaluating and recording information related to the risk of harm from human activities on VECs, this framework may be used as a key information tool to identify management priorities for PNCIMA and MPAs and inform the development of more specific conservation objectives, management strategies and action plans including monitoring, research and management assessments as appropriate.

This framework is intended to be a tool in a broader toolbox for the evaluation of priorities and development of management objectives in PNCIMA and Pacific Region MPAs. Outputs from the ERAF will be integrated in decision-making along with stakeholder input, outputs from other decision support tools, legislative and regulatory responsibilities and policy priorities into final management direction for these areas. An outline of where the ERAF fits into a broader adaptive management (AM) framework in Pacific Region is shown in Figure 1, although this general framework may be modified depending on management needs. VECs are identified during the ecosystem assessment and characterization step (Step 1) in the AM framework (Figure 1) and these VECs may be used in the ERAF, providing a strong linkage between the AM framework and the ERAF.

Stakeholder engagement and input are critical throughout the adaptive management cycle, and stakeholders are expected to be involved in several aspects of the risk assessment process as shown in Figure 1.

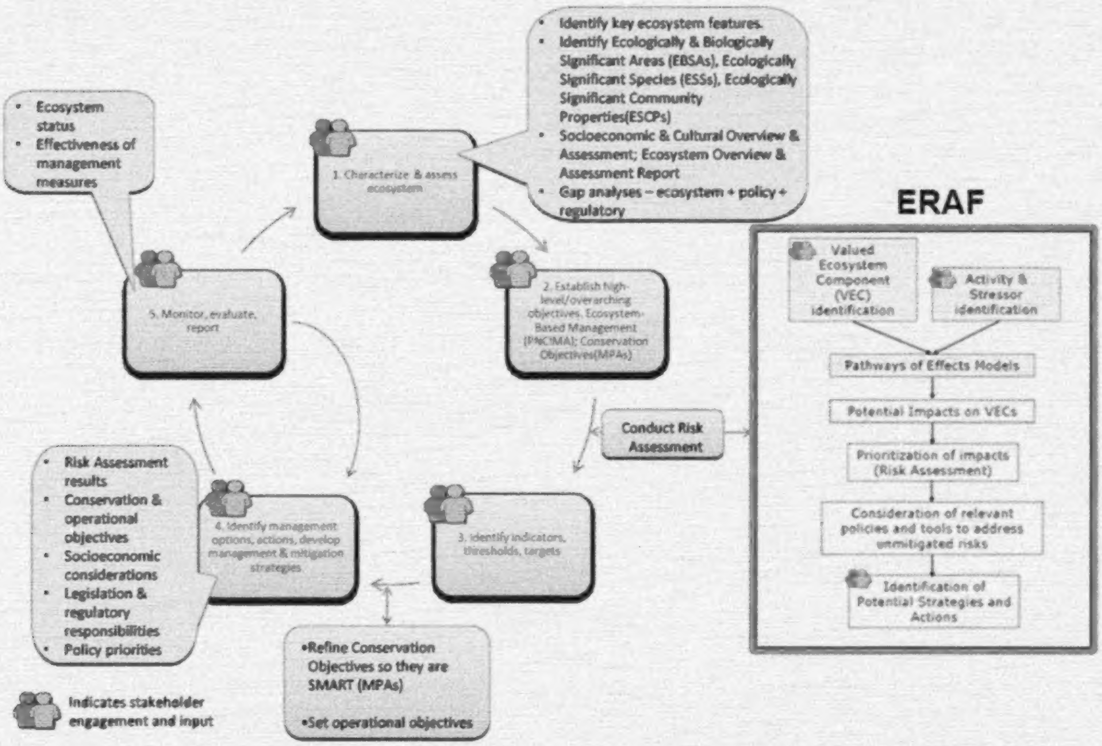

Figure 1. Overview of DFO Oceans – Pacific Region adaptive management (AM) framework and the relationship of the ERAF to this framework.

Development of the ERAF was guided by best practices and recommendations from risk assessment processes in other countries and risk frameworks developed within DFO for other purposes. The ERAF focuses solely on ecological VECs (not social or economic) and uses Pathways of Effects (PoE) models to identify mechanistic linkages between human activities and stressors impacting VECs. Use of the ERAF is expected to facilitate the communication of the relative risk of ecological consequences of anthropogenic stressors on VECs, ranking of those risks, and discussion of acceptable levels of risk to VECs.

This ERAF does not identify the most appropriate management responses to risk(s) or the societal costs and benefits associated with managing ecosystem risks nor does it provide a

probabilistic assessment of absolute risk at the first two risk assessment levels. However, it explicitly considers uncertainty in communicating risk scores at different stages, which may inform management strategies and actions.

1.1 INTRODUCTION TO MPAS AND PNCIMA

The ERAF developed in this paper is intended to be applied to both Marine Protected Areas (MPAs) and the PNCIMA.

MPAs are geographically defined areas in the marine environment dedicated and managed for the long-term conservation of nature. Fisheries and Oceans Canada (DFO) designates MPAs under the Oceans Act in order to protect and conserve:

- Commercial and non-commercial fishery resources, including marine mammals, and their habitats;
- Endangered or threatened marine species, and their habitats;
- Marine areas of high biodiversity or biological productivity;
- Unique habitats; and
- Any other marine resource or habitat as is necessary to fulfill the Minister's mandate (e.g., Scientific Research)

A single overarching Conservation Objective (CO) outlining the key components that require protection has been developed for each MPA in the Pacific Region. These COs focus on factors that are significant about the system and are guided by those factors outlined in the list above. Although the wording of COs differs between MPAs (Appendix A), examples of key components that they identify include protection and conservation of biodiversity, productivity and ecosystem function (Table 1).

Table 1. Summary of the use of different terms in conservation objectives of the two MPAs (Bowie Seamount and Endeavour Hydrothermal Vents) and Areas of Interest (Glass Sponge Reefs and Race Rocks) assigned by DFO in the Pacific Region.

Term used in Conservation Objective	Bowie Seamount (~15,000km^2)	Endeavour Hydrothermal Vent (~100km^2)	Glass sponge reefs (~1,000km^2)	Race Rocks (~2.7km^2)
Biodiversity	✓	✓	✓	✓
Productivity	✓	✓		
Natural diversity		✓		
Ecosystem function			✓	✓
Dynamism		✓		
Structural habitat			✓	

MPAs in the Pacific region encompass a broad range of sizes (Table 1), though they are relatively small when compared to the larger scale of the PNCIMA (~102,000km^2).

The PNCIMA extends from Canada's northern border with Alaska south to Bute Inlet on the mainland, across to Campbell River on the east side of Vancouver Island and Brooks Peninsula on the west side of Vancouver Island. The western boundary is the base of the continental shelf slope. These boundaries were determined based on oceanographic processes, watershed boundaries that influence the marine area, and the northern political boundary with the USA.

PNCIMA is unique due to its diverse ocean ecosystems, which provide critical habitat for many species and marine resources that contribute to coastal economies and communities. A wide variety of year-round and seasonal activities occur in the offshore and coastal areas. In the nearshore areas, a much broader range of activities take place, including traditional fishing and food gathering, aquaculture, ecotourism, utility and communications lines, ports, ferry landings, and community harbours. The goal of the PNCIMA initiative is to ensure a healthy, safe and prosperous ocean area by engaging all interested parties in the collaborative development and implementation of an integrated management plan for PNCIMA.

Specific conservation objectives have not been developed for PNCIMA, unlike MPAs, but guidance is provided by the draft Ecosystem-Based Management (EBM) goals and provisional objectives (DFO 2013b). A key EBM goal for PNCIMA is the "*integrity of marine ecosystems in PNCIMA primarily with respect to their structure, function and resilience*". The provisional objectives related to this goal are:

1. *Biological diversity*: Conserve the diversity of species, viable populations, and ecological communities and their ability to adapt to changing environments;
2. *Productivity:* Conserve the productivity, trophic structure, and mean generation times of populations so ecosystem components can play their natural role in the food web;
3. *Physical environmental quality:* Conserve habitat and water quality of the ecosystem; and
4. *Cumulative effects:* Manage negative cumulative effects that affect ecosystem components.

2 ANALYSIS

The ERAF was developed to estimate the potential risk of harm to VECs from human activities and their associated stressors and has two key phases:

1. Scoping:
    - Identification of the key features or properties of the system (VECs), including species, habitats and community/ecosystem properties;
    - Identification of the activities and stressors that have the potential to affect these VECs using Pathways of Effects models (PoEs); and,
2. Risk assessment:
    - Assessing the risks of harm to each VEC from each activity and associated stressors singly and cumulatively using appropriate criteria and scoring methodology.

An overview of the methodology used in this ERAF is outlined in Figure 2.

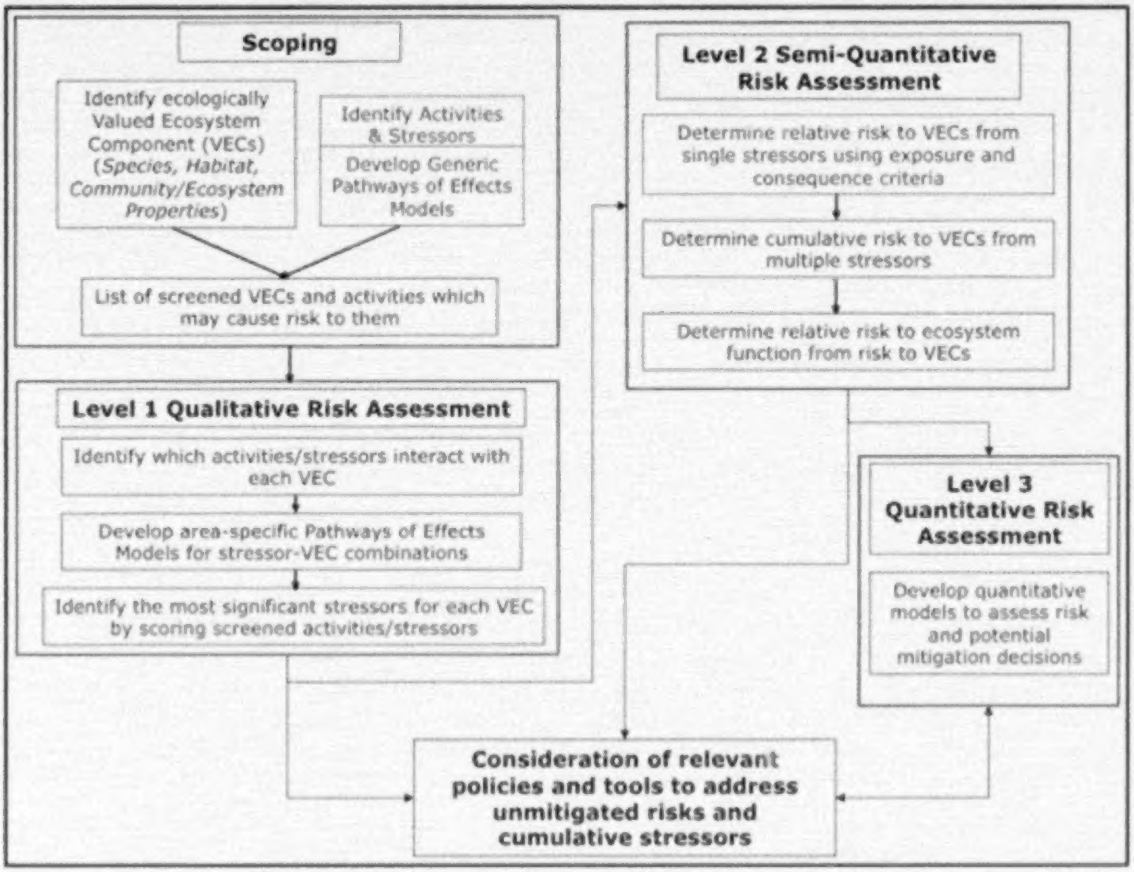

Figure 2. Methodology for the proposed Pacific Region Ecological Risk Assessment Framework for Ecosystem-Based Management.

Risk assessment can be used to screen and rank a list of issues (based on stressors or ecological component vulnerabilities), or it can be more complex and thorough such as with quantitative risk analysis (e.g., stock assessments). All applications of the ERAF described in this document begin with a mandatory scoping phase, followed by the risk assessment phase, which has three different levels. After the scoping phase, activities and stressors can either go through a Level 1 assessment and on to the more intensive and increasingly quantitative analyses at Levels 2 and 3 (Figure 2) or they may proceed directly into a Level 2 or 3 assessment, bypassing the lower levels, depending on management needs for the ERAF outputs, i.e., the risk assessment phase is not necessarily a linear process proceeding from Level 1 to Level 2 to Level 3. Hence, the different levels of risk assessment can be applied independently (i.e., modularly) or in series (i.e., hierarchically), depending on the question(s) asked and the availability of data, since the higher level risk assessments impose greater data requirements on users. A Level 1 assessment is a comprehensive but largely qualitative analysis of risk, a Level 2 assessment provides a more focused and semi-quantitative analysis, and a Level 3 assessment is a highly focused and fully quantitative "model-based" assessment of risk. If the framework is applied hierarchically, then many activities and stressors with potentially low ecological risks may not go beyond Level 1. Caution is needed to ensure that the screening out of multiple low risk stressors at Level 1 does not result in the screening out of significant cumulative effects on VECs.

The magnitude and sources of uncertainty are documented and reported alongside risk scores at each level of the risk assessment to aid in interpretation of the risk profile for each VEC (defined in Section 2.1.1). The risk scores, calculated during the different stages of the risk assessment, can be used to rank VECs and/or activities and stressors that may require enhanced management attention.

A significant advantage of the ERAF is that it is scalable and adaptable to different management needs. For example, a Level 1 risk assessment could be used as a rapid assessment tool for developing priorities, while a complete Level 2 assessment would likely provide sufficient detail for managers to develop specific indicators of success for a particular management action, or assess the potential cumulative effects of current activity in an area.

The ERAF is intended to address biological VECs, although non-biological criteria (e.g., social, economic) could be used to define VECs, depending on the needs of managers. Incorporation of non-biological criteria is not explicitly addressed, yet stakeholder engagement and input is depicted at various stages of the overall Pacific Region adaptive management (AM) framework (Figure 1) and the VEC selection process (Figure 3). However, this flexibility in defining VECs may have operational impacts in applying the framework since, for example, the choice of criteria used for habitat and community screening prior to a Level 1 risk assessment may be dependent on the choice of VECs.

The framework ranks VECs at risk and the degree and source of risk to those VECs, but it does not identify the most appropriate management responses to these risk(s) and it is not intended to provide an assessment of absolute risk in the first two levels, nor does it include an assessment of societal benefits associated with assuming ecosystem risks.

2.1 SCOPING

The scoping phase is the first element in the ERAF (Figure 2), and requires all the relevant information about the area of interest to be collected and structured in order to inform and set the boundaries for subsequent risk analyses. In this phase, the VECs for the area of interest, and human activities and the associated stressors potentially affecting VECs are identified. These VECs may be externally defined at the first step in the AM framework (see Figure 1).

The scoping phase consists of the following steps:

1. Identifying VECs for the area of interest; and
2. Identifying activities, associated stressors, and generic pathways of effects models

Further detail on the procedure used for each of these steps follows.

2.1.1 Identifying Valued Ecosystem Components (VECs)

The term Valued Ecosystem Component (VEC) was coined in the 1980s to provide focus for environmental impact assessments (Beanlands and Duinker, 1983). A VEC is defined by the Canadian Environmental Assessment Agency (CEAA) as an environmental element of an ecosystem that has scientific, social, cultural, economic, historical, archaeological or aesthetic importance. VECs are finding increasing application in environmental management (Leschine and Petersen, 2007) and have been used in several processes with different goals. For example, the Puget Sound Nearshore Partnership process chose a cross-section of organisms and physical structures as VECs in order to communicate the value of nearshore restoration to managers and the public (Leschine and Petersen 2007). The focus of the ERAF described in this document is on VECs of ecological significance to an area in order to inform DFO's implementation of ecosystem-based oceans management. From hereon in this document, reference to VECs indicates only VECs of ecological significance.

The steps taken to select VECs are:

1. Structure the ecosystem into components and subcomponents of species, habitats, and community/ecosystem properties, and
2. Identify criteria to select Valued Ecosystem Components (VECs).

2.1.1.1 Structuring the Ecosystem: Species, Habitats, and Community/Ecosystem Properties

VECs are often visualized as a species or a group of organisms. However, habitats and ecosystem properties are critical and sustaining aspects of an ecosystem that are commonly overlooked as VECs. To identify and classify VECs in a comprehensive way, we provide an overall structure for the ecosystem by incorporating both the process developed by the Australian ERAEF (Hobday et al. 2007; 2011; Williams et al. 2011) and the Puget Sound Nearshore Partnership (Leschine and Petersen 2007; Neuman et al. 2009; Kerschner et al. 2011). The result is a set of components, subcomponents and sample relevant measures to structure the ecosystem and help identify and classify VECs (Table 2).

The resulting scheme organizes ecosystems into three component groups: species, habitats and community/ecosystem properties, for which definitions are given in Section 2.1.1.2. Each of these component groups are further broken down into subcomponents, for which examples of relevant measures are provided (Table 2). These components and subcomponents are representative of the objectives identified in Goal 1 of the PNCIMA planning process, as well as MPA conservation objectives. The intention is that these component categories and sub-component categories will be inputs into the risk assessment, and will be used to determine relative cumulative risk to ecosystem structure and function from a suite of activities and stressors.

Table 2. Structuring ecosystem components: subcomponents and sample relevant measures used to structure the ecosystem.

Ecosystem Component Category	Sub-component	Sample Relevant Measures
SPECIES		
	Population size	Number of individuals Population density Biomass per unit area
	Population condition	Organism condition Age/size structure Genetic diversity and structure Spatial distribution of population Reproductive capacity Behaviour / Movement
HABITAT		
	Extent of habitats	Spatial distribution of habitat (aerial extent, % cover)
	Condition of habitats	Habitat structure (patchiness, morphology) Substrate Quality Water quality Air quality

Ecosystem Component Category	Sub-component	Sample Relevant Measures
COMMUNITY/ECOSYSTEM PROPERTIES		
	Community composition	Species diversity Species composition Species evenness Functional group / guild composition Spatial distribution of the community Trophic diversity
	Ecosystem processes	Primary production Nutrient cycling Oceanographic processes Flows of organic and inorganic matter

2.1.1.2 Selecting Valued Ecosystem Components (VECs)

Although all species, habitats and communities have some degree of ecological significance, it is important to identify those components with greater relative significance because they may require enhanced management or risk averse policies for management. Where possible, criteria or guidelines were developed for each ecosystem component category (species, habitats and communities) in order to screen the initial ecosystem components to identify those with greater relative significance (or 'value') and select VECs for PNCIMA and MPAs (Figure 2).

The process for selecting valued ecosystem components (VECs) is outlined in Figure 3. To guide the selection of the initial ecosystem components, we refer to MPA conservation objectives and the draft EBM goal for PNCIMA outlined in the introduction - to maintain the integrity of marine ecosystems with respect to their structure, function and resilience, including biodiversity, productivity, trophic structure, and habitat.

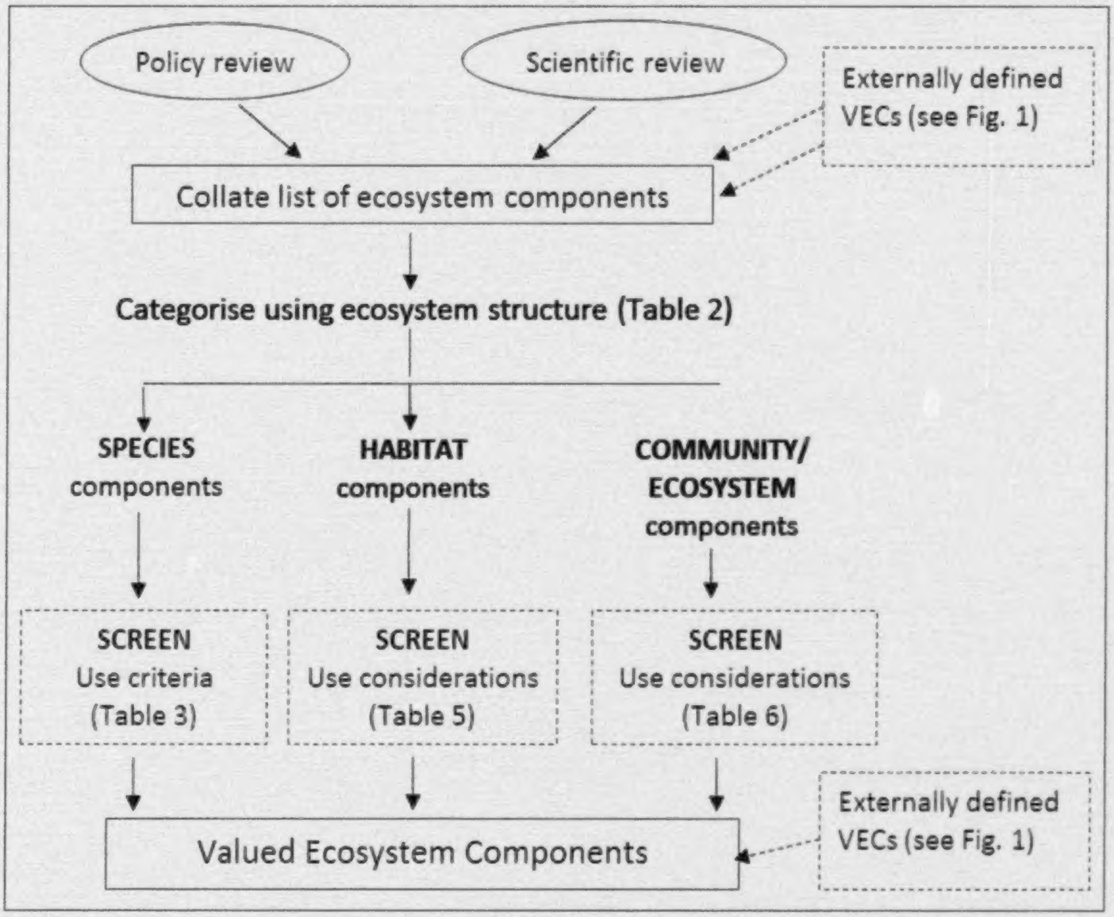

Figure 3. Outline of process to identify Valued Ecosystem Components

The next section provides more detailed descriptions of how we define the three ecosystem component categories (species, habitats and communities/ecosystem properties), and the criteria or considerations used to screen ecosystem components.

Externally identified VECs such as those defined by socio-economic criteria, can be incorporated into the process either at the collating step (see Figure 3), where they will be screened against the criteria in Tables 3 and 4, or alternatively into the last step where the two VEC lists should be compared and contrasted.

Species

British Columbia has some of the highest marine biodiversity in Canada, with at least 5,000 marine species described (not including bacteria) (Archambault et al. 2010), but potentially up to 14,000 species present (.J. Boutillier, Fisheries and Oceans Canada, pers. comm.). Since it is not practical to subject a large number of species to the ERAF process, criteria were developed to identify those species VECs whose relative ecological significance is perceived to be highest due to their:

1. Role in the ecosystem (e.g., habitat creating species, keystone species),
2. Status as species of conservation concern,

3. Uniqueness, or
4. Sensitivity.

Table 3 contains additional details of the criteria used for species. These criteria were chosen in order to select species components for their ecological value with one exception - target and non-target fishery species impacted beyond their sustainable level, which are identified under depleted species.

The initial lists of species and species groups are developed by applying the criteria listed in Table 3 to a set of species synthesized from the ecologically and biologically significant areas (EBSA) process (Clarke and Jamieson 2006), the BC Marine Conservation Analysis atlas (BCMCA 2011), the Province of BC Valued Marine Ecosystem Features document (Dale 1997), and a list of Threatened /Endangered/ Protected species listed under SARA/COSEWIC/ IUCN/BCCDC (see glossary). The initial list also includes species suggested by DFO policy and oceans, stakeholders and First Nations, and is supplemented by species identified by a comprehensive scientific literature review, as some groups such as marine invertebrates are under-represented on the lists of conservation organizations. Species meeting at least one criterion in Table 3 are screened into the ERAF process. Since the screening process does not rank VECs, species meeting multiple criteria are not treated differently than species meeting a single criterion.

Table 3. Criteria for selecting relevant species components.

Species Criteria	Description
Nutrient Importer/Exporter	Crucial role in maintaining ecosystem structure and function through the transfer of energy or nutrients that would otherwise be limiting to an ecosystem.
Specialized or keystone role in food web	Species has a highly specialized relationship with another species or guild; has an important food web relationship where an impact to it would cause vertical or horizontal change in food web; species supports a temporally or spatially explicit event important for other species. Examples include highly influential predators and forage species (see glossary for definitions).
Habitat creating species	Species which create habitat for infauna and aerate substrates. Species which create habitat on the seafloor and water column.
Rare, Unique, or Endemic Species	Existence of a species at relatively low abundance or whose populations are globally or nationally significant within the boundaries of the area of interest.
Sensitive Species	Low tolerance and more time needed for recovery from stressors.
Depleted Species	Listed under SARA/COSEWIC/IUCN/BCCDC Target and non-target species impacted beyond their sustainable level by fisheries.

Habitats

Habitats can be defined in many ways, but one of the simplest is the area or environment where an organism or ecological community normally lives or occurs.

Habitats not only represent the fundamental ecological unit in which species interact, but it is the matrix that supports an essential range of ecological processes. The loss or impairment of

habitat integrity can result in direct impacts to species, communities and ecosystem structure and function (Bax et al. 1999; Bax and Williams 2001).

Determining which habitat types to include in a risk-based assessment framework is challenging unless extensive habitat lists based on standardized classifications are available (e.g. Hobday et al. 2007; Williams et al. 2011). Ideally, a bioregional classification system is used to define or classify habitats because it enables the description of habitat types with higher levels of certainty, which increases the effectiveness of the risk assessment and subsequent management processes. In Australia, habitat types were selected based on seabed imagery or, if these images were not available, a more inferential method relying on photographic data from similar areas, biological survey data, GIS mapping of bathymetry, and coarse scale geomorphology is used (Hobday et al. 2007; Williams et al. 2011). Several approaches have been applied to Pacific Region waters including the Province of BC process to identify areas of representivity and special features, the BC Marine Ecological Classification (BCMEC) scheme (Howes et al. 2001), which classifies habitats or ecounits based on a set of two attributes for pelagic systems and seven attributes for benthic systems (Table 4), and the marine atlas and analysis recently produced by BCMCA (2011). For nearshore coastal habitats, the Shorezone process identifies shoreline types using physical and biological attributes (Howes et al. 1995). At present, there is no consensus within Fisheries and Oceans on a systematic approach to define habitat units for the Pacific Region waters. However, a bioregional classification for Pacific Region waters is scheduled to be completed in 2013. Until this classification scheme becomes available, the habitat components within PNCIMA are based on the physical and biological units derived from the Important Areas (IA) process used to identify ecological and biologically significant areas (EBSAs) in Pacific Region (e.g., Clarke and Jamieson 2006a,b). This approach to identifying habitat components will need to be updated as progress is made to classify habitat types within PNCIMA. Other approaches can also be incorporated to support the selection of habitat types. A good example of such an approach is the BCMEC classification system, which is used to identify physical habitat types (Table 4).

Table 5 lists some considerations to take into account when selecting habitat components. Although these considerations are quite general, more specific criteria for selecting habitats will depend upon the management questions being asked.

Table 4. Attributes used to identify pelagic and benthic habitat types by the BCMEC (adapted from Howes et al. 2001).

Ecounit	Variables	Classes
Pelagic	Stratification	Tidal mixing Mixed Weakly-mixed Stratified
	Salinity (surface)	Mesohaline Polyhaline Euhaline
Benthic	Depth	Shallow Photic Mid-depth Deep Abyssal
	Wave Exposure (nearshore)	High Moderate Low
	Relief	High Medium Low
	Slope	Flat

Ecounit	Variables	Classes
		Sloping Steep
	Tidal Current (nearshore)	High Low
	Temperature (bottom)	Warm Cold
	Substrate	Hard Sand Mud Unknown

Table 5. Considerations for selecting relevant habitat components.

Habitat Considerations	Description
Biogenic habitat types	Habitats formed by biogenic species.
Rare or unique habitats	Habitat types with very restricted distribution in the area of interest, or habitats which are globally or nationally significant within the boundaries of the area of interest.
Sensitive habitats	Habitats with low tolerance to disturbance requiring more time to recover, or no tolerance to disturbance. May be fragile habitat, such as biogenic coral. The loss or impairment of habitat integrity can result in direct impacts to species, communities and ecosystem structure and function.
Habitats critical for sensitive species	Habitats supporting species with low tolerance which need more time for recovery from stressors.
Threatened or depleted habitats	Habitats in danger of disappearance in their natural range. Determined from literature reviews, expert review, or relevant conservation lists.
Habitats critical for depleted species	Habitats critical for supporting species listed under SARA/COSEWIC/IUCN/BCCDC and target and non-target species impacted beyond their sustainable level.
Habitats critical for supporting rare, unique or endemic species	Habitats supporting species at relatively low abundance or whose populations are globally or nationally significant within the boundaries of the area of interest.
Habitats supporting critical life cycle stages	For example, habitat important for the shelter, feeding, spawning and rearing of seamount associated fish.
Habitats providing critical ecosystem function(s) or service(s)	Habitats that provide critical physical, chemical, and biological processes or functions that contribute to the self-maintenance of an ecosystem. Ecosystem services are the beneficial outcomes, for the natural environment or people, which result from ecosystem functions.

Community/Ecosystem properties

Community and ecosystem properties are aspects of the ecosystem that capture community attributes (e.g., species diversity, trophic diversity, functional redundancy) and ecosystem properties (e.g., primary production, nutrient cycling) (Table 2). We have adopted a broad definition of community properties that includes species diversity (which encompasses species richness, species diversity, species evenness), community composition (which describes the relative abundance or biomass of different species in the community), functional or guild redundancy (which refers to replication in the number of species that perform similar ecosystem functions), trophic diversity (relative abundance or biomass of primary producers and consumers in the food web), and functional diversity (number of functional groups that are

present in the system) (Kershner et al. 2011). Ecosystem properties refer to ecological processes such as primary production and nutrient cycling, in addition to flows of organic and inorganic matter throughout a food web. While some of these properties and dynamic processes can be captured by the species and habitat VECs, others require specific, distinct definitions as VECs.

At present, there is very little guidance on how to best capture significant community and ecosystem properties as VECs. As there is only sporadic and very limited information on the range of communities present in PNCIMA, guidance for the selection of communities at this stage of the process has not been formulated yet. At the spatial scale of an MPA, community and ecosystem properties that are significant to the ecosystem can be identified, for example, by selecting the functional groups that best represent that ecosystem (e.g., the composition of functional groups for a kelp forest community as identified in Micheli and Halpern (2005)). These examples are meant as guidance at this stage, but more information about how to select the most appropriate community and ecosystem properties at different spatial scales will be necessary to populate the ERAF. Table 6 lists some factors to consider when selecting community / ecosystem property components. As with habitat components, more specific criteria for selecting community / ecosystem properties will depend upon the management questions being asked.

Table 6. Considerations for selecting relevant community/ecosystem property components.

Community / Ecosystem Property Considerations	Description
Unique communities	Communities (species assemblage) that are unique within the region, or within the area of interest.
Ecologically significant community properties	Communities that are ecologically "significant" because of the functions that they serve in the ecosystem and/or because of features that they provide for other parts of the ecosystem to use (EBSA national document definition).
Functional groups which play a critical role in ecosystem functioning	Biodiversity and productivity of functional groups which are central to the functioning and resilience of the ecosystem.
Ecological processes critical for ecosystem functioning	Ecological processes which are central to the functioning of the ecosystem. Include oceanographic factors critical to ecosystem functioning. Material flows, or the cycling of organic matter and inorganic nutrients (e.g., nitrogen, phosphorus), can mediate how energy travels through the food web.
Sensitive functional groups	Functional groups which are sensitive to disturbance, and if impacted would result in significant effects on community composition and ecosystem function. Includes functional groups with low functional redundancy, and low response diversity. For example, a food web containing several species of herbivores would be considered to have high functional redundancy with respect to the ecosystem function of grazing, if species of herbivores show a differential response to hypoxia, there is also high response diversity.

2.1.2 Identifying Activities, Associated Stressors, and Generic Pathways of Effects Models

The second step in the scoping phase is to identify activities and stressors and evaluate potential impacts of anthropogenic activities in the area using Pathways of Effects models (PoEs). A PoE model is a representation of cause-and-effect relationships between human activities, their associated stressors, and their impacts. PoE models have been identified by Fisheries and Oceans Canada as a central tool (DFO 2011) and are being developed to provide the background information needed for several risk analysis processes.

Because PoE models illustrate cause-effect relationships and identify the mechanisms by which stressors ultimately lead to effects in the environment, PoE s can help managers prioritize and focus resources on activities with the greatest potential to produce negative effects on ecosystems. These models are developed using the best available information (ideally from peer reviewed literature) on how activities influence the environment. A PoE model consists of two principal components: a diagram that illustrates the relationships between the human activities, stressors and impacts on ecological components, and a supporting document that describes the predicted relationships among those elements along with the rationale and sources of information used for their selection (DFO 2011).

The PoE approach is recommended for the ERAF because it provides a visual and transparent model of the impacts of an activity or stressor on VECs. Peer reviewed PoE models are preferred, but the pool of such models is limited at present. In the absence of a PoE model, the best available information should be used and other methods or models should be explored, such as the Driver-Pressure- State-Impact-Response (DPSIR) and Bayesian models.

PoE models can take various forms, depending on the scale, users, and degree of detail needed for particular management purposes. For integrated and ecosystem-based management (IM/EBM), three categories of PoE models have been or are being developed within DFO to address different analysis goals and objectives: 1) holistic models, 2) endpoint models, and 3) activity/action and sector-based models (DFO 2011). For the purposes of this ERAF, we propose to use activity-based PoE models.

Activity-based PoE s

Activity-based PoE models describe the relationship between a specific activity, its associated stressors and their impacts. This kind of model is currently used by the DFO Fisheries Protection Program to describe development proposals in terms of the activities that are involved, the type of cause-effect relationships that are known to exist, and the mechanisms by which stressors ultimately lead to effects in the aquatic environment.

For the ERAF described in this paper, we separate the activity-based PoEs into *generic* and *area-specific* categories. Here at the scoping stage, generic PoEs are utilised to illustrate the relationship between a specific activity, the stressors it generates, and potential impacts (Figures 4 and 5). The results of this application ideally identifies the activities most likely to cause effects of concern.

Area-specific PoEs are utlilised later in the Level 1 risk assessment, and apply the generic PoEs representing those activities identified as having potential risk to a chosen VEC or set of VECs for a specific area of interest (i.e., MPA or PNCIMA). Area-specific PoEs are described later in Section 2.2.1.2 (Figures 6 and 7).

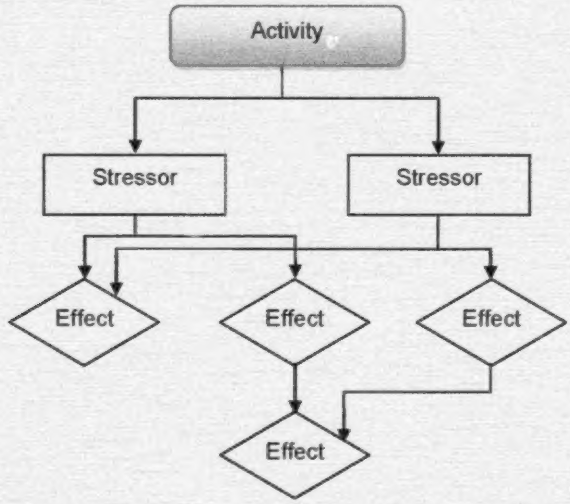

Figure 4. Structure of an activity-based Pathway of effects general template (a generic type).

An example of a generic activity-based PoE model for the use of explosives is provided in Figure 5. Each pathway in the PoE represents an area where it may be possible to apply mitigation measures to reduce or eliminate a potential effect.

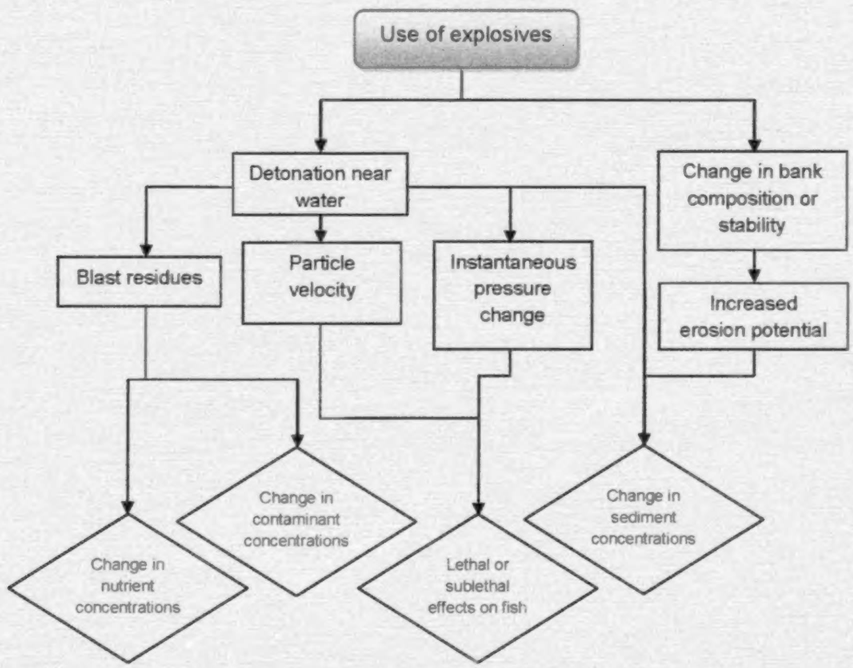

Figure 5. Example of a generic activity -based pathways of effects model based on the use of explosives in the marine environment (DFO 2011).

Overall, the national objective is to develop various types of PoE models to be used to inform decision-makers within an integrated management (IM) context as well as other environmental processes such as Environmental Assessments (EAs). Although MPA and PNCIMA PoE models are being developed in the short-term to serve current needs (i.e., activity-based

models), there is a longer-term need to create a virtual library of peer-reviewed PoEs available for general use at any spatial scale.

2.2 RISK ASSESSMENT

Risk assessment is an analytical approach for estimating risk, which is defined as the likelihood that a VEC will experience unacceptable adverse consequences due to exposure to one or more identified stressors. By providing a systematic and transparent process for gathering, evaluating and recording information related to the risk of harm to VECs from human activities and associated stressors, risk assessment tools can provide science advice on ranking VECs that may assist resource managers in making decisions by providing a better understanding of the relationships between stressors and potential ecosystem impacts.

Risk assessment as used in this ERAF evaluates the degree to which human activities and their associated stressors interfere with the achievement of broad EBM and conservation objectives related to particular VECs in MPAs or PNCIMA. In order to meet these objectives, risk assessments need to be: conducted relatively quickly, scalable to varying spatial scales, adaptable to data limitations, address uncertainty, and easily updateable and flexible.

A marine ecosystem-based risk assessment is based on an understanding of the distribution and intensity of activities occurring on land and sea as well as the impacts these activities will have on VECs. The ERAF aims to:

- Identify which activities and stressors potentially impact VECs;
- Rank risks in order to efficiently filter out those activities and stressors that are lower risk and/or those VECs that show lower vulnerability to stressors; and
- Identify the mechanisms by which different activities and stressors impact different VECs and their subcomponents, which can be useful for identifying both cumulative effects and for guiding mitigation strategies.

In the introduction to Section 2 we explain how the framework can be used either as a hierarchical progression from Level 1 to Level 2 to Level 3 (Figure 2), or it can be used modularly, choosing the level of assessment that best suits the question(s) asked and the availability of data. The hierarchical approach leads to rapid identification of high-risk activities, which in turn can lead to immediate management responses. This approach has been guided by other risk assessment exercises, including the Australian Ecological Risk Assessment for the Effects of Fishing (ERAEF) frameworks (Hobday et al. 2007, 2011; Williams et al. 2011), risk frameworks developed for other DFO LOMAs (Park et al. 2010; Hardy et al. 2011), the InVEST habitat risk framework (Tallis et al. 2011), and frameworks applied in the US (Patrick et al. 2009, Samhouri and Levin 2012); as well as other DFO risk assessment frameworks (e.g. Holt et al. 2012; DFO 2013a). However, if the ERAF is applied in this way to screen in high-risk activities at the Level 1 assessment, then many activities and stressors with potentially low ecological risks may not go beyond Level 1. Caution is needed to ensure that the screening out of multiple low risk stressors at Level 1 does not result in the screening out of potentially significant cumulative effects on VECs. If the focus is on cumulative effects and if more quantitative data is available, then the framework should be applied modularly, proceeding directly into a Level 2 or 3 assessment and bypassing the lower levels.

Uncertainty must be clearly described when communicating risk scores at different levels because clear documentation of uncertainty will inform the interpretation of these scores. Uncertainty can occur during exposure (e.g., overlap in space and time between a VEC and activity/stressor is not known) or in terms of consequences (e.g., nature and magnitude of acute or chronic response) and may be related to data gaps or knowledge gaps (e.g., the mode of

action of a particular stressor). Communicating the drivers of uncertainty as explicitly as possible (exposure, consequence) is important as it may guide management strategies and actions.

The following sections describe the steps involved in assigning risk for Levels 1 and 2 of the risk assessment scheme. Level 3 is a fully quantitative model-based risk assessment to determine the cumulative impacts to VECs from multiple stressors, but specific models are not identified because the choice of model will be based on the VEC and cumulative stressors identified in the Level 2 risk assessment. The first step of the risk assessment phase is to incorporate the information resulting from the scoping stage into the risk assessment process, starting with the Level 1 qualitative risk assessment.

2.2.1 Level 1—Qualitative Risk Assessment

A Level 1 risk assessment is based on qualitative information, scientific literature, and expert opinion and is used to provide a rapid assessment of vulnerable VECs and the activities and stressors that potentially impact these VECs. The goal of a Level 1 assessment is to ensure that the risks of harm from all potential activities/stressors are considered, while at the same time focuses maximum effort on further analysis of those VECs most at risk.

The steps taken in Level 1 of the risk assessment are:

1. Determining which activities and associated stressors potentially interact with each VEC;
2. Developing area-specific PoE models; and,
3. Selecting the most significant stressors for each VEC;

2.2.1.1 Determining Which Activities and Associated Stressors Potentially Interact With Each VEC

A list of potentially unique activities and associated stressors impacting VECs can be created by qualitatively evaluating the spatial and temporal interactions between activities and ecosystem components. The results of this process for each VEC are recorded in Table 7 using a binary scoring system, where a score of 1 identifies all activities and stressors that are present and may potentially be harmful, and a score of 0 is used for all stressors or activities that are absent or whose impacts are negligible. For example, land-based pollution, sea level rise, and coastal erosion may result in harm to some VECs occupying shallow coastal habitats, but are generally considered to be of low impact in offshore areas. Only those activities and stressors that scored a 1 (present) are analyzed in the next step. As part of the documentation for this process, a short rationale should be provided to explain why each activity was either screened in or out of the risk assessment.

Table 7. Matrix of activities/stressors and potential VECs

		Valued Ecosystem Component			
Activity	**Stressor**	1	2	3...	n
Activity 1	Stressor 1	1	0	0	1
	Stressor 2	0	0	0	1
	Stressor 3...	0	0	1	0
	Stressor n	0	0	0	0
Activity 2	Stressor 1	1	0	0	0
	Stressor 2	0	1	1	0
	Stressor 3...	0	1	0	0
	Stressor n	0	0	0	0

Activity	Stressor	Valued Ecosystem Component			
		1	2	3...	n
Activity 3...	Stressor 1	0	0	0	0
	Stressor 2	1	0	0	0
	Stressor 3...	0	0	0	0
	Stressor n	0	0	0	0
Activity n	Stressor 1	1	0	0	0
	Stressor 2	1	1	0	0
	Stressor 3...	1	0	0	0
	Stressor n	0	0	0	0

2.2.1.2 Developing Area-Specific Pathways of Effects Models

The next stage in a Level 1 assessment is to utilize area-specific PoE models to identify cause-and-effect relationships between those human activities that were screened in during the scoping phase and any impacts they may have on the specific VECs and their subcomponents. An example of the structure of an area-specific PoE model is given in Figure 6.

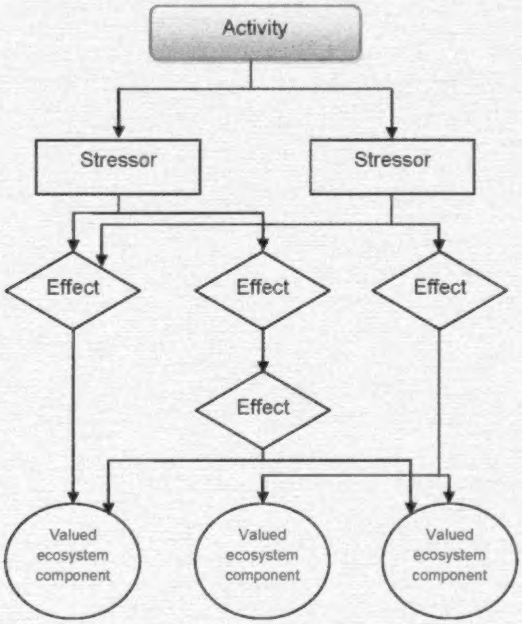

Figure 6. Example of the structure of an area-specific Pathways of Effects model. Note that stressors (rectangle), impacts of stressors (diamonds), and VECs (circles) are identified by different symbols in these models.

A key consideration in designing an area-specific PoE model is the spatial unit (or spatial scale) where human activities, their associated stressors, and effects on VECs will occur. Spatial units can be as expansive as a large ocean management area (LOMA) such as PNCIMA, or as contained as a marine protected area (MPA), a single estuary or a species-specific habitat. Theoretically, PoEs can be developed for any spatial scale. However, the complexity of a PoE model will differ depending on the spatial scale at which the model is built (local, regional or national) and the degree of detail to be included. The use of area-specific PoEs helps to identify

those activity-stressor linkages which are likely to increase the risk of harm to VECs and provide the focus for the next phase of the risk assessment.

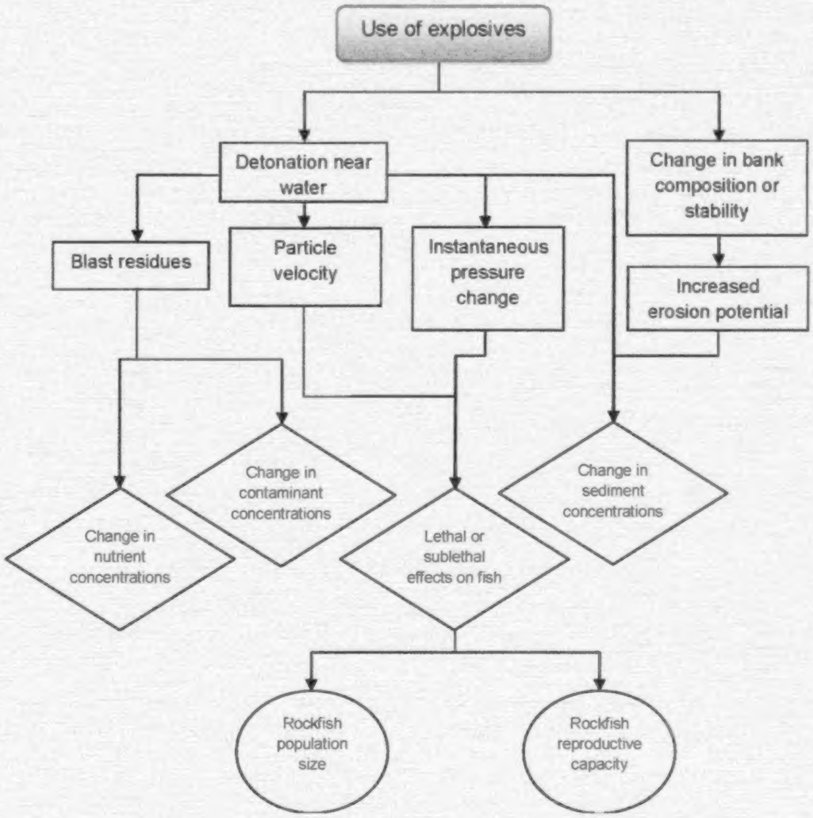

Figure 7. Example of an area-based Pathways of Effects model illustrating the lethal or sub-lethal effects of explosives on two rockfish VECs (population size and reproductive capacity).

2.2.1.3 Selecting the Most Significant Stressors for Each Valued Ecosystem Component (VEC)

The next step is to qualitatively score the activities and stressors screened into the risk assessment (i.e., those that were scored 1) for each VEC. For each activity and stressor, the specific PoE model is used to determine which of the subcomponents for each VEC has the potential to be impacted by the activity and associated stressors. For example, if the use of explosives is known to have lethal and sub-lethal effects on fish, the subcomponents that will be examined in the Level 1 risk assessment may be population size and reproductive capacity of rockfish (e.g., the rockfish example in Figure 7 and see Appendix B for guidance on scoring consequence for different subcomponents).

Building on the concepts of other risk-assessment frameworks, a framework was developed for evaluating the risk of stressors associated with various human activities on VECs based on two axes of information. The first axis is related to the exposure of a VEC to stressors associated with particular human activities, and the second axis is related to the impact of an activity on a VEC, given its exposure.

The terms are scored qualitatively in Level 1 of the ERAF. The framework follows the same general structure of other qualitative risk assessments with some modifications and guidance on

the scoring of the two terms of the risk assessment (***QExposure*** and ***QConsequence***). The **QRisk** score estimated for a VEC as a result of exposure to a given stressor(s) is calculated as:

Equation 1: $QRisk_{sc} = QExposure_{sc} \times QConsequence_{sc}$

Where:

QExposure$_{sc}$ is a measure of how much the activity or stressor interacts with the stressor and its level of intensity. ***QExposure***$_{sc}$ is scored based on three sub terms: (i) the level of intensity of the plausible worst-case scenario of the stressor; (ii) the temporal scale of the interaction; and (iii) the spatial scale of the interaction. The sublevels of intensity and spatial scale are scored from 1 to 3 while temporal scale is scored from 1 to 4, with low scores indicating low intensity or little temporal or spatial overlap. The three scores are multiplied to derive a raw QExposure score ranging from 1 to 36 for all of the possible combinations of the sub terms. The raw QExposure scores are then binned on a scale of 1-6 (Table 8) and the binned ***QExposure***$_{SC}$ is used in subsequent calculations of overall risk. The rationale for the selected binned score should be included in the documentation of the process.

QConsequence$_{sc}$ represents the potential for long-term harm[1] to a VEC as a result of interaction with stressor and is estimated based on recent (last ten years) data or science-based predictions for the next ten years. Activities/stressors that are expected to increase to a point where they can cause serious and irreversible harm should be screened in to the process, even if the current level of harm is minimal.

Table 8. Scoring rubric for QExposuresc. where two rows are given under for single score, the score can be selected if either row is appropriate.

Description			Raw Score	Binned Score
Intensity	**Temporal scale**	**Spatial Scale**		
1 (Low)	1 (Rare)	1 (Few restricted locations)	1	1
1 (Low)	1 (Rare)	2 (Localized)	2	1
1 (Low)	2 (Relatively often)	1 (Few restricted locations)	2	1
2 (Moderate)	1 (Rare)	1 (Few restricted locations)	2	1
1 (Low)	1 (Rare)	3 (Widespread)	3	2
1 (Low)	3 (Frequent)	1 (Few restricted locations)	3	2
3 (High)	1 (Rare)	1 (Few restricted locations)	3	2
1 (Low)	2 (Relatively often)	2 (Localized)	4	2
1 (Low)	4 (Continuous)	1 (Few restricted locations)	4	2
2 (Moderate)	1 (Rare)	2 (Localized)	4	2
2 (Moderate)	2 (Relatively often)	1 (Few restricted locations)	4	2
1 (Low)	2 (Relatively often)	3 (Widespread)	6	3
1 (Low)	3 (Frequent)	2 (Localized)	6	3
2 (Moderate)	1 (Rare)	3 (Widespread)	6	3
2 (Moderate)	3 (Frequent)	1 (Few restricted locations)	6	3
3 (High)	1 (Rare)	2 (Localized)	6	3

[1] Long-term harm is defined by FAO as 20 years or 2 generations, whichever is greater.

Description			Raw Score	Binned Score
Intensity	Temporal scale	Spatial Scale		
3 (High)	2 (Relatively often)	1 (Few restricted locations)	6	3
1 (Low)	4 (Continuous)	2 (Localized)	8	3
2 (Moderate)	2 (Relatively often)	2 (Localized)	8	3
2 (Moderate)	4 (Continuous)	1 (Few restricted locations)	8	3
1 (Low)	3 (Frequent)	3 (Widespread)	9	3
3 (High)	1 (Rare)	3 (Widespread)	9	3
3 (High)	3 (Frequent)	1 (Few restricted locations)	9	3
1 (Low)	4 (Continuous)	3 (Widespread)	12	4
2 (Moderate)	2 (Relatively often)	3 (Widespread)	12	4
2 (Moderate)	3 (Frequent)	2 (Localized)	12	4
3 (High)	2 (Relatively often)	2 (Localized)	12	4
3 (High)	4 (Continuous)	1 (Few restricted locations)	12	4
2 (Moderate)	4 (Continuous)	2 (Localized)	16	4
2 (Moderate)	3 (Frequent)	3 (Widespread)	18	4
3 (High)	2 (Relatively often)	3 (Widespread)	18	4
3 (High)	3 (Frequent)	2 (Localized)	18	4
2 (Moderate)	4 (Continuous)	3 (Widespread)	24	5
3 (High)	4 (Continuous)	2 (Localized)	24	5
3 (High)	3 (Frequent)	3 (Widespread)	27	5
3 (High)	4 (Continuous)	3 (Widespread)	36	6

QConsequence$_{SC}$ scores are selected from Table 9 and should include a rationale supporting the choice. The consequence score is determined based on the most sensitive subcomponent identified for the VEC in the specific PoE model (see Appendix B for guidance on scoring consequence for different subcomponents). Following the explosives example above, if explosives are known to cause mortality of fish and also affect reproductive capacity, then whichever subcomponent is most sensitive becomes the basis for scoring in the Level 1 risk assessment.

*Table 9. General Scoring rubric for **QConsequence$_{sc}$** See Appendix B for specific guidance on scoring for QConsequencesc for different subcomponents*

Description	**Score**
Negligible impact on population/habitat/community	1
Minimal impact on population/habitat/community structure or dynamics	2
Maximum impact that still meets an objective (e.g. sustainable level of impact such as a full exploitation rate for a target species; maintaining levels of critical habitat)	3
Wider and longer term impacts (e.g. long-term decline in CPUE)	4

Description	Score
Very serious impacts occurring, with a relatively long time period likely to be needed to restore to an acceptable level (e.g. serious decline in spawning biomass limiting population increase)	5
Widespread and permanent/irreversible damage or loss will occur-unlikely to ever be fixed (e.g. local extinction)	6

Next, an overall risk value ***QRisk$_{SC}$*** is calculated as the product of the ***QExposure$_{SC}$*** and ***QConsequence$_{SC}$*** scores (Equation 1), producing possible risk values between 0 and 36. These QRisk values are classified into five risk categories, ranging from negligible to extreme (Table 10), using the qualitative risk categories developed by Fletcher et al. (2005). These categories identify the level of risk and allow for screening of those activities and stressors that should be considered in the next phase of the risk assessment for each of the VECs. While all activities and stressors relevant to the VECs can be examined in the next phase, it is recommended that only those activities and stressors that are scored in the moderate range or higher (7-36) be considered for the Level 2 risk assessment phase in order to maintain the scope of assessment at a manageable level. However, VECs with low or negligible scores to single stressors that are exposed to multiple stressors may be placed in the extreme category due to cumulative scores, and should be considered in the next phase (Level 2) of the risk assessment.

Table 10. Risk categories and scoring (modified from Fletcher et al. 2005).

Risk category	Value	Recommended Action
Negligible	0	No need to proceed to the next phase of risk assessment. Short justification needed.
Low	1 to 6	No need to proceed to the next phase of risk assessment. Full justification needed.
Moderate	7 to 12	Proceed with Level 2 risk assessment. Full performance report needed.
High	13 to 20	Proceed with Level 2 risk assessment. Full performance report needed.
Extreme	20 to 36	Proceed with Level 2 risk assessment. Full performance report needed.

For each QRisk score, an uncertainty value is recorded. The information used at this level is qualitative and each step is based on expert judgment. The uncertainty values and categories shown in Table 11 are based on the scheme used by Therriault and Herborg (2008) and Therriault et al. (2011). For VECs in which uncertainty is high while Qrisk scores fall below the moderate range, reporting should describe the drivers of the uncertainty scores and these VECs and activities/stressors should be considered for the Level 2 Risk Assessment phase.

Table 11. Uncertainty categories and scoring (modified from Therriault and Herborg (2008), and Therriault et al. (2011)).

Uncertainty Category	Score	Description
Very low uncertainty	1	Extensive scientific information; peer-reviewed information; data specific to the location; supported by long-term datasets (10 years or more).

Uncertainty Category	Score	Description
Low uncertainty	2	Substantial scientific information; non-peer-reviewed information; data specific to the region; supported by recent data (within the last 10 years) or research.
Moderate uncertainty	3	Moderate level of information; first hand, unsystematic observations, or older data (more than 10 years) from the area of interest; data are third party, from comparable regions.
High uncertainty	4	Limited information; based on third-party observational information or circumstantial evidence.
Very high uncertainty	5	Little or no information; based on general knowledge.

An example Level 1 risk assessment scoring outcome for a hypothetical VEC is given in Table 12. The exposure and consequence terms in columns 2 and 3 are multiplied to calculate **QRisk** (column 4), and then categorized as negligible, low, moderate, high, or extreme (column 4). Cumulative risk can then be calculated by summing the **QRisk** column (see Section 2.2.2.2.2 for discussion on cumulative risk). The last column records the uncertainty associated with the **Qrisk** score.

Table 12. Example Level 1 risk assessment scoring for a hypothetical VEC and a hypothetical set of activities and stressors. Uncertainty follows scoring in Table 11.

Key Activity/Stressor	QExposure	Qconsequence	**QRisk** QExp x QCon	**QRisk** Risk Category	**Uncertainty**
Activity 1 (Stressor 1)	5	5	25	Extreme	5
Activity 2 (Stressor 1)	1	2	2	Low	4
Activity 3 (Stressor 2)	3	3	9	Moderate	3
Activity n (Stressor 1)	2	3	6	Low	2
Activity n (Stressor 2)	4	1	4	Low	3
Activity n (Stressor 3)	5	3	15	High	1
	CumQRisk = ∑(QRisk)		61		

The next phase in the risk assessment is a semi-quantitative approach that categorises risks to the ecosystem by examining the scale and intensity of stressors associated with human activities and the resulting change and sensitivity of VECs exposed to those stressors.

2.2.2 Level 2—Semi-Quantitative Risk Assessment

2.2.2.1 Structure of the General Risk Framework

The ERAF is intended to assess risks to ecosystem components (i.e., VECs) at different spatial scales, for example PNCIMA as a whole, or selected MPAs. It is intended to assess three types of risk:

1. The relative risk (***$Risk_{SC}$***) to a VEC from the different stressors that affect it within the area assessed;
2. The cumulative risk **(*$CRisk_C$*)** to a VEC from the different stressors that affect it within the area assessed; and

3. The relative risk to ecosystem function (***ERisk**$_{C;}$**; RoleRisk**$_{SC}$*) within the area assessed from the loss of the different VECs included in the risk assessment.

Relative risk to a VEC estimates the impact on a VEC from the different stressors acting singly within a given area, and allows for relative ranking by comparing the impact of stressors on a suite of VECs. This measure cannot be used outside the chosen area. Cumulative risk incorporates relative risk to a VEC from more than one stressor, and can be used to determine overall risk to a given VEC. Ecosystem risk is a reinterpretation of a VEC's cumulative risk (see Section 2.2.2.2.2) based on the component's perceived contribution to ecosystem structure and function. Calculation of each of these types of risk will be described in detail in the following sections.

The actual distribution of VECs and stressors in nature does not necessarily conform to boundaries establish by human values or views; thus, both the impacts and risks to VECs are likely not fully defined by interactions within areas such as MPAs or PNCIMA. Because of this mismatch, the risk estimation described here provides a relative assessment of risks within the spatial domain chosen for assessment. Consequently, while it can address the three purposes listed above, the results can only be used to compare risks within the assessment area, and cannot be used to compare risks with areas outside the assessment spatial boundaries.

2.2.2.2 Computation of Risk

2.2.2.2.1 Risk to a VEC from a Single Stressor

The risk to VECs from stressors associated with various human activities is evaluated based on two axes of information: Exposure and Consequence. The first axis is related to the exposure of a VEC to stressors associated with particular human activities, and the second axis is related to the consequence to a VEC resulting from exposure to the activities. The framework follows the same general structure and scoring dimensions of other risk assessments with some modifications and more specific guidance on the scoring of the subcomponents of the two principal terms of the risk assessment (***Exposure*** and ***Consequence***). The risk to a given VEC (c), from exposure to a given stressor (s) is calculated as:

Equation 2: $$Risk_{sc} = Exposure_{sc} \times Consequence_{sc}$$

Where:

- ***Exposure**$_{SC}$* is the estimated magnitude of interaction between the stressor (s) and VEC (c); and
- ***Consequence**$_{SC}$* represents the potential for long-term harm to the VEC as a result of interaction with the stressor and is estimated from metrics that represent the capacity of the VEC to resist and/or recover from exposure to the stressor (i.e., resistance and resiliency of the VEC to change).

***Exposure**$_{SC}$* is estimated based on a series of metrics that define the probability of interaction between the stressor and the VEC, and the estimated proportion of the VEC that is exposed to the stressor(s). These subterms are scored on a scale of 0.1 to 10 equating to a scaled percentage, and then the overall ***Exposure**$_{SC}$* score is re-scaled to scores of 1-4 using quartiles.

***Consequence**$_{SC}$* is estimated based on a change in the VEC in response to acute and chronic effects of a stressor, and the VECs' recovery potential. The sub terms are scored on a scale from 1-3, equating to benchmarks of low, medium, and high risk. The final ***Consequence**$_{SC}$* score is re-scaled to scores of 1-4 using quartiles.

Both ***Exposure***$_{SC}$ and ***Consequence***$_{SC}$ are scored on scales of 1-4 so that each term is given equal weight in the calculation of ***Risk***$_{SC}$ score.

The metrics of ***Exposure***$_{SC}$ and ***Consequence***$_{SC}$ are discussed below in sections 2.2.2.2.3 and 2.2.2.2.4 respectively. The calculation of ***Risk***$_{SC}$ for each of the stressors affecting a given VEC enables comparison of the relative risk to the VEC resulting from the different stressors.

2.2.2.2.2 Cumulative Risk to a VEC from Multiple Stressors

In its simplest form, in which all stressors that impact a VEC are additive, the cumulative risk (***CRisk***$_{C}$) from multiple stressors is simply the sum of the risks over the set of stressors that impact the VEC.

Equation 3: $$CRisk_c=\sum_{s=1}^{n}(Exposure_{sc}\times Consequence_{sc})$$

Where:

n = the number of stressors that impact the VEC.

However, cumulative effects can be of four general types: additive, synergistic, compensatory, and masking. Synergistic effects magnify the consequence of individual stressors to produce a joint consequence that is greater than their additive impacts/risks. Conversely, compensatory effects produce a joint consequence that is less than additive, and masking effects produce essentially the same consequence for the VEC as would occur with exposure to one of the stressors alone. Thus the estimation of cumulative risk will require an assessment of how the effects arising from different stressors interact.

In the absence of information regarding the accumulation of effects from multiple stressors on a VEC, additivity is assumed as a reasonable first approximation for estimating cumulative risk. Meta-analysis examining cumulative effects from multiple stressors found that most interactions are additive (Crain et al. 2008). Furthermore, the additivity assumption is precautionary in the sense that it will overestimate cumulative risk for effects that are compensatory or masking. However, it will underestimate risk when effects are synergistic. Consequently, consideration of the potential for synergistic risks is important. Estimation of ***CRisk***$_{C}$ across a set of VECs enables evaluation of the relative risk to the VECs within the area assessed. The general approach to calculating cumulative risk, which includes consideration of synergistic effects and can be applied to compensatory and masking effects, is discussed below in section 2.2.2.2.8.

2.2.2.2.3 Calculating Terms of Risk of Exposure to a Single Stressor (Risk$_{SC}$***)***

Equation 4: $$Exposure_{SC} = PExposed_{SC} \times Intensity_{SC}$$

Where:

PExposed$_{SC}$ is the proportion (%) of the component exposed to the stressor, and ***Intensity***$_{SC}$ is an estimate of the intensity of the stressor.

PExposed$_{SC}$ is calculated as:

Equation 5: $$PExposed_{SC} = \%Areaoverlap_{SC} \times \%Depthoverlap_{SC} \times \%Temporaloverlap_{SC}$$

Where ***PExposed***$_{SC}$ is the product of ***%Area overlap***$_{SC}$, ***%Depth overlap***$_{SC}$ and ***%Temporal overlap***$_{SC}$. All of these terms are scored on a scale from 0.1-10 (e.g., a $_{C}$ or a ***%Depth overlap***$_{SC}$ of 5 corresponds to 50% overlap of the stressor and VEC in the area or depth, and a 5 for ***%Temporal overlap***$_{SC}$ corresponds to 6 months of overlap between the stressor and

VEC). Estimation of the ***%Area overlap$_{SC}$*** takes into account seasonal aggregations (e.g., if the VEC is highly aggregated for a portion of the time that the stressor and VEC overlap, this would be given a higher score to reflect the increased exposure). Similarly, estimation of ***%Depth overlap$_{SC}$*** takes into account depth and terrain barriers (e.g., slopes) that may limit interaction of, for example, fishing gear contact with habitats. ***%Temporal overlap$_{SC}$*** is simply the fraction of the year in which the stressor overlaps with the VEC.

If quantitative information about the overlap of VECs and stressors is limited, then a precautionary qualitative scoring procedure that reflects the bins in Table 13 can be used. This qualitative scoring sets the ***PExposed$_{SC}$*** scores based on the 75% point of the range for each attribute (Low: 0-20%; Medium: 20-50%; High 50-100%). Therefore, the 'Low' bin would be scored 15%, the 'Medium' bin would be scored 41%, and the 'High' bin would be scored 88%. These bins are based on the InVEST habitat risk assessment scoring guidelines for overlap of stressors and habitats (Tallis et al. 2011). In the absence of information, evidence or logical argument to the contrary concerning overlap between VECs and stressors, a precautionary approach is recommended, and risk should be set as high.

Intensity$_{SC}$ is a measure of the level of effort/density of an activity or stressor (Park et al. 2010) such as fishing effort/frequency within the period of temporal overlap, estimated density of debris, quantity or concentration of a pollutant or harmful species. Scoring is relative to an estimated worst-case scenario for the stressor on a scale of 0.1-10 corresponding to the estimated percentage of the worst-case. Similar to scoring for ***PExposed$_{SC}$***, in the absence of quantitative information about intensity of stressors, a qualitative scoring procedure that reflects the bins listed in Table 13 can be used. In the absence of any information, evidence, or logical argument to the contrary about intensity, a precautionary approach is recommended, and risk should be set as high.

Table 13. Qualitative scoring guidance for sub terms of Exposure.

Description	**Exposure**		
	Low (0-20%)	**Medium (20-50%)**	**High (>50%)**
Pexposed			
% Area Overlap, measured as overlap of the stressor and VEC	15%	41%	88%
% Depth Overlap, measured as the vertical overlap of the stressor and VEC; takes into account depth and terrain barriers (e.g. slopes) that may limit interaction of stressor with VECs.	15%	41%	88%
% Temporal Overlap, the fraction of the year in which stressor overlaps with the VEC	15%	41%	88%
Intensity			
Intensity, a measure of the intensity of the stressor, scored as effort or density	15%	41%	88%

Exposure$_{SC}$ is then calculated as the product of ***PExposed$_{SC}$*** and **Intensity$_{SC}$** (Equation 4) and is rescaled to values between 1-4 (using quartiles from Table 14), to ensure equal weighting of

terms in the risk calculation. The quartiles are based on all outcomes of the exposure equation and then split using 25, 50 and 75 percentiles.

*Table 14. **Exposure$_{sc}$** scores calculated as the product of **PExposed$_{sc}$** and **Intensity$_{sc}$** and rescaled to a scale of 1-4 using quartiles.*

Pexposure x Intensity Score	Exposure Score
0.0001 to 68.6	1
68.7 to 271.8	2
271.9 to 827.1	3
827.1 to 10000	4

***2.2.2.2.4 Calculating** Consequence$_{SC}$*

Equation 6: $Consequence_{SC} = (AcuteChange_C + ChronicChange_C) \times Recovery_C$

Where:

AcuteChange$_C$ is measured as the percent change in population-wide average mortality rate of a species when exposed to a given stressor.

ChronicChange$_C$ is measured as the percent change in condition, fitness, genetic diversity, of a population.

AcuteChange$_C$ and ***ChronicChange$_C$*** both represent the percent change of the VEC in response to stressors. In some cases a single stressor may impose both acute and chronic effects (e.g., mortality and fitness consequences on biogenic habitats from fishing gear, mortality and fitness consequences to species and habitats from contaminants or oil spills). When scoring qualitatively, resistance to change, as well as duration of the effect from the stressor should be considered when estimating the % change resulting from exposure to the stressor.

Both terms are scored on a scale of 1-3 as having low, medium, or high risk where: Low = <10% change; Medium = 10%-30% change; High = >30% change.

Scoring of ***AcuteChange$_C$*** for habitats should attempt to consider loss of productive capacity rather than loss of area only and thus both loss of habitat area, and fragmentation in the sense of reduced productive capacity should be considered. (Fragmentation in regard to inhibition of recovery is included in the estimation of ***Recovery$_C$***). When estimating ***AcuteChange$_C$***,

fragmentation is a multiplier for reduced productive capacity of habitats. For example 5 ha of habitat that are distributed contiguously may not have the same productive capacity as 5 ha which are distributed in patches. If information is available to indicate the degree of productive capacity loss associated with fragmentation, then this information should be used to fractionally increase the estimated change.

*Calculating **Recovery$_C$***

Recovery$_C$ represents the recovery time for the component to return to a pre-stress level once the stressor is removed. In many cases it is unlikely that this time will be known; thus, this term is scored on a set of attributes that reflect the productivity or sensitivity of the component. The value of the ***Recovery$_C$*** term is calculated as the average of the criteria ratings.

*Calculating **Recovery$_C$** for Species VECs*

The productivity attributes and scoring guidelines for species VECs are listed in Table 15. These attributes were chosen for their applicability across multiple species types in ecosystems and were adopted from Hobday et al. (2007), and Samhouri and Levin (2012). However, for fish species, a set of additional attributes are recommended, which include those employed by Hobday et al. (2007, 2011), and in aggregate are an indicator of the intrinsic population growth rate (r) (Table 15).

Table 15. Attributes for assessing potential risks to species posed by activities and stressors.

Description	**Consequence** **Low (1)**	**Medium (2)**	**High (3)**
Resilience factors			
Acute Change, measured as the percent change in population-wide average mortality rate of a species when exposed to a given stressor.	<10%	10-30%	>30%
Chronic Change, measured as the percent change in condition, fitness, genetic diversity, of a population.	<10%	10-30%	>30%
Recovery factors			

Description	Consequence Low (1)	Medium (2)	High (3)
Fecundity, the population-wide average number of offspring produced by a female each year	>100,000	100-1000	<100
Breeding strategy, (indexed using Winemiller's (1989) method) provides an indication of the level of mortality that may be expected for offspring in the first stages of life	<1	1 to 3	>3
Recruitment pattern, success frequency; populations with sporadic and infrequent recruitment success are often long-lived and thus may be expected to have lower levels of productivity. Recruitment success is defined as frequency of recruitment greater than the long-term average level	>75%	10-75%	<10%
Natural mortality rate, insrantaneous mortality rate; populations with naturally higher instantaneous mortality rates likely have higher recovery rates	>0.4	0.2-0.4	<0.2
Age at maturity, population-wide average number of offspring produced by a female year	<2 years	2-4 years	>4 years
Life stage, the life stage(s) affected by a stressor; if stressor affects individuals before they have the opportunity to reproduce, recovery is likely to be inhibited	Not affected or only mature stages	Only immature stages	All stages
Population connectivity, realized exchange with other populations based on spatial patchiness of distribution, degree of isolation, and potential dispersal capability	regular (not a distinct DPs or ESU)	occasional	negligible (DPS or ESU)
Listed status, describes the status of protected, species of concern, threatened or endangered species for COSEWIC/SARA/IUCN species. If not listed or not under consideration do not include this term in the calculation	Data deficient	Species of Concern	Endangered or Threatened
Additional recovery factors for fish (Hobday et al 2007)			
Maximum age	<10 years	10-30 years	>30 years
Maximum size	<60 cm	60-150cm	>150cm
von Bertalanffy growth coefficient (k)	>0.25	0.15-0.25	<0.15

*Calculating **Recovery**$_C$ for Habitat VECs*

The attributes of benthic habitats used to assess the potential risks posed by activities are listed in Table 16. This table lists the criteria for ranking the attributes and includes supporting information and decision rules. The recommended attributes for habitats are drawn primarily from two risk frameworks: InVEST (Tallis et al. 2011), and Samhouri and Levin (2012).

Table 16. Attributes for assessing potential risks to habitats posed by activities and stressors.

Description	Consequence Low (1)	Medium (2)	High (3)
Resilience factors			

Description	Consequence Low (1)	 Medium (2)	 High (3)
Acute Change, measured as the percent change in population-wide average mortality rate of a species when exposed to a given stressor.	<10%	10-30%	>30%
Chronic Change, measured as the percent change in condition, fitness, genetic diversity, of a population.	<10%	10-30%	>30%
Recovery factors			
Fecundity, the population-wide average number of offspring produced by a female each year	>100,000	100-1000	<100
Breeding strategy, (indexed using Winemiller's (1989) method) provides an indication of the level of mortality that may be expected for offspring in the first stages of life	<1	1 to 3	>3
Recruitment pattern, success frequency; populations with sporadic and infrequent recruitment success are often long-lived and thus may be expected to have lower levels of productivity. Recruitment success is defined as frequency of recruitment greater than the long-term average level	>75%	10-75%	<10%
Natural mortality rate, instantaneous mortality rate; populations with naturally higher instantaneous mortality rates likely have higher recovery rates	>0.4	0.2-0.4	<0.2
Age at maturity, population-wide average number of offspring produced by a female year	<2 years	2-4 years	>4 years
Life stage, the life stage(s) affected by a stressor; if stressor affects individuals before they have the opportunity to reproduce, recovery is likely to be inhibited	Not affected or only mature stages	Only immature stages	All stages
Population connectivity realized exchange with other populations based on spatial patchiness of distribution, degree of isolation, and potential dispersal capability	regular (not a distinct DPs or ESU)	occasional	negligible (DPS or ESU)
Listed status, describes the status of protected, species of concern, threatened or endangered species for COSEWIC/SARA/IUCN species. If not listed or not under consideration do not include this term in the calculation	Data deficient	Species of Concern	Endangered or Threatened
Additional recovery factors for fish (Hobday et al 2007)			
Maximum age	<10 years	10-30 years	>30 years
Maximum size	<60 cm	60-150cm	>150cm
von Bertalanffy growth coefficient (k)	>0.25	0.15-0.25	<0.15

Calculating ***Recovery$_C$*** *for Community VECs*

The attributes of benthic communities used to assess the potential risks posed by activities are listed in Table 17. This table lists the criteria for ranking the attributes and includes supporting information and decision rules. For communities the recommended attributes are drawn from Hobday et al. (2007).

Table 17. Attributes for assessing potential risks to communities posed by activities and stressors.

Description	Consequence Low (1)	Medium (2)	High (3)
Resilience factors			
% of species impacted, higher number of species impacted, greater consequence	<10%	10-30%	>30%
% of functional groups impacted, greater number of functional groups impacted, greater consequence	<10%	10-30%	>30%
% decrease in total abundance per functional group, higher decline in abundance, greater consequence	<10%	10-30%	>30%
% decrease in taxonomic distinctness, greater loss of taxonomic distinctness, greater consequence	<10%	10-30%	>30%
Recovery factors			
Species richness (S), Higher richness, more resistant and faster recovery	Relative measure for species richness is high	Relative measure for species richness is medium	Relative measure for species richness is low
Taxonomic distinctness, (presence/absence data) Δ* index represents the breadth of taxonomic diversity in a sample; higher taxonomic distinctness suggests higher resistance	Relative measure for taxonomic distinctness is high	Relative measure for taxonomic distinctness is medium	Relative measure for taxonomic distinctness is low
% of functional groups with total number of members per group >5 or 10, more groups, less susceptible	>50%	30-50%	<30%
Abundance per functional group, (Higher abundance per functional group, more resilient)	Relative abundance is high	Relative abundance is medium	Relative abundance is low

2.2.2.2.5 Calculating Consequence$_{SC}$ *Score*

As shown in Equation 6, **Consequence$_{SC}$** is calculated as the sum of $AcuteChange_v$ and $ChronicChange_v$ multiplied by **Recovery$_C$**. This formula results in scores that range from 1-18. To get the final **Consequence$_{SC}$** value, these preliminary scores are re-scaled to values between 1-4 (using quartiles from Table 18), to ensure equal weighting of terms in the risk calculation. The quartiles are based on all outcomes of the consequence equation and then split using 25, 50 and 75 percentiles.

Table 18. Rescaling Consequence$_{SC}$ score on a scale of 1-4 using quartiles.

(AcuteChange + ChronicChange) x Recovery	Consequence Score
2 to 6.33	1
6.34 to 8.00	2
8.01 to 9.4	3
9.5 to 18	4

2.2.2.2.6 Calculating Uncertainty for Level 2 Risk Assessment

It is important to capture and communicate uncertainties associated with risk estimation in a Level 2 risk assessment. For each of the terms of the $\boldsymbol{Risk_{SC}}$ score, $\boldsymbol{Exposure_{SC}}$ and $\boldsymbol{Consequence_{SC}}$, an uncertainty score should be recorded using the categories in Table 11. For interactions where uncertainty is high, the main factor(s) contributing to the uncertainty score should be recorded (e.g., lack of comprehensive data, lack of expert agreement, predictions based on future scenarios which are difficult to predict) to guide further research or work.

An example scoring for level 2 risk assessment is given in Appendix C. The scores assigned to the sub terms for $\boldsymbol{Exposure_{SC}}$ and $\boldsymbol{Consequence_{SC}}$ are listed in Table A4, and the equations for $\boldsymbol{Exposure_{SC}}$, $\boldsymbol{Consequence_{SC}}$ and $\boldsymbol{Risk_{SC}}$ are calculated in columns 6, 21 and 22, respectively.

2.2.2.2.7 $CRisk_C$ with Non-additive Interactions

If the cumulative effect of a set of two or more stressors on a given VEC is either synergistic, compensatory or masking, then risk to the component is estimated for the set of stressors rather than separately for each stressor and summed. The recommended approaches are described below.

For synergistic effects: a) estimate the risk for each stressor; b) select the stressor with the highest risk rating; c) estimate the proportional increase in risk which will be greater than the sum of the risks; and, d) carry this risk estimate into Equation 3 along with the risk estimates for other stressors that are additive within the set.

Compensatory effects: the same approach is used for compensatory effects as for synergistic effects, except that the cumulative risk of the set of stressors will be less than the sum of the individual risk estimates.

Masking effects: carry the largest individual risk estimate for stressors within the set of stressors into Equation 3 along with the risk estimates for other stressors that are additive within the set.

2.2.2.2.9 Relative Risk to Ecosystem Structure and Function

In the risk framework developed by Park et al. (2010), sensitivity of the ecosystem to the loss of a VEC is included as a sub-term in the calculation of the sensitivity term in their risk equation. While an important consideration in considering risk to a VEC, this approach is qualitatively distinct from other sensitivity sub-terms in that it reflects the importance of the VEC to the ecosystem rather than the sensitivity of the VEC to a given stressor.

Instead of including an ecosystem sensitivity sub-term in the calculation of $\boldsymbol{Risk_C}$, and hence $\boldsymbol{Crisk_C}$, we propose a separate step to estimate the risk to ecosystem structure and function that results from risk to different VECs. There are two ways to approach this risk estimation.

Approach 1 – Ecosystem Risk Associated with Risks to Individual VECs

The first approach involves estimating the ecosystem sensitivity to the loss of each VEC across a set of criteria (ecosystem roles). Once $\boldsymbol{Crisk_C}$ has been estimated for a series of VECs, then the relative risk to the ecosystem can be assessed by comparing values of ecosystem risk ($\boldsymbol{ERisk_C}$) associated with the cumulative impacts on the VECs, calculated as

Equation 7: $$ERisk_C = CRisk_C \times ESensitivity_C$$

Where:

$\boldsymbol{ESensitivity_C}$ represents the relative sensitivity of the ecosystem to harmful impacts to the VEC (after Park et al. 2010).

ESensitivity$_C$ for a given VEC is calculated as the weighted sum over a set of criteria of ecological roles/functions served by the VEC. The scoring for the ecological function criteria is binary, i.e., a score of 0 is assigned if the VEC does not serve in the role, or 1 if it does. Thus,

Equation 8:

$$ESensitivity_C = \sum_{R=1}^{n} w_R \; x \,\{0|1\}_{RC}$$

Where:

W_R = weight for role R,

$\{0|1\}_{RC}$ = the VEC (C) score for Role (R), and

N = the number of role criteria.

These criteria need to be defined and could correspond to a set of ecological roles, or ecosystem functions. For example, Samhouri and Levin (2012) illustrate the application of their risk assessment framework using ecosystem function or food web criteria, namely: Simpson Diversity, Ecosystem-wide consumption, Ecosystem-wide respiration/ecosystem-wide biomass, Net primary production/ecosystem-wide biomass, and Resilience (ecosystem reorganisation index). Other ecosystem role criteria that could be employed in this risk estimation can be drawn from those used in this framework for selecting the VECs (i.e., the first three criteria in Table 3).

If an alternative to the binary scoring system is used in the calculation of ***ESensitivity$_C$***, then appropriate weightings will need to be developed. Weights would be developed using a Delphic process to provide initial estimations using a pair-wise comparison of criteria across the possible pairings of role criteria, and the Analytic Hierarchy Process (Saaty, 1990) used to develop a final set of consistent weights (Appendix D).

Approach 2 – Ecosystem Risk Associated with Defined Ecosystem Structure and Functions

The second approach to calculate the risk to ecosystem structure and function is to estimate the potential risk of loss in ecosystem structure and function, using the aforementioned set of defined ecological roles or functions. Here estimates are compiled within each role across the set of VECs that contribute to that function. The risk estimate corresponds to the fraction of the ecosystem structure or function at risk, i.e.,

Equation 9:

$$RoleRisk_R = \sum_{C=1}^{n} w_C \; x \; \frac{\sum_{C=1}^{n} Crisk_C}{\sum_{C=1}^{n} Crisk_{MAX,C}} \; x \; 10$$

Where:

RoleRisk$_R$ = the fraction of the ecosystem structure or function at risk, on a scale of 0 – 10,

Crisk$_v$ = the cumulative risk score for VEC$_v$,

Crisk$_{MAX,C}$ = the maximum possible value of ***Crisk*** for VEC$_c$,

w_C = a weight for VEC *c*, that corresponds to its estimated proportional contribution to *Role $_R$* across the full set of VECs that contribute to the *Role (i.e.,* not just those VECs included in the level 2 analysis), and

n = the number of VECs included in the level 2 analysis that serve in the role assessed.

Only VECs that serve in a given ecosystem role or function are included in the computation of risk to that role or function.

2.2.3 Level 3—Quantitative Risk Assessment

A fully quantitative assessment of risks or impacts is undertaken at Level 3 of the framework in order to determine the cumulative impacts to VECs from multiple stressors. It is not our goal at this stage to develop new quantitative approaches for the DFO Pacific Region. Instead we highlight some of the methodologies that can be applied at this stage of the risk assessment. For example, single species stock assessment models could be utilised, particularly those that include environmental and human impact factors other than direct capture from fishing. Other more rapid assessment techniques can be used for species for which quantitative stock assessments are not available, such as the Sustainability Assessment for Fishing Effects (SAFE) method (Zhou and Griffiths 2008; Zhou et al. 2011). The SAFE method has been applied in fisheries assessments in Australia to assess and manage the impacts of fishing on multiple species, particularly non-target species and to establish biological reference points (Zhou and Griffiths 2008; Zhou et al. 2011). This method is similar to formal quantitative stock assessments, but estimates fishing mortality rates from multiple activities and uses life history traits to establish reference points.

Quantitative risk assessment encounter-response models can be used to examine the risk from specific threats such as assessments of trawling and re-suspension of sediment (J. Boutillier, Fisheries and Oceans Canada, pers. comm.) or assessments of the effects of fishing on seabirds (Tuck et al. 2011)). Other examples include population models or population viability analyses (PVA), which can be used to assess impacts to VECs from multiple stressors (e.g., Bolten et al. 2011).Quantitative benthic species impact models could be applied to habitat and community components (Ellis et al. 2008) and Ecopath and Ecosim models could be used to address impacts to community and ecosystem properties (Christensen et al. 2005). Ultimately, the appropriate model will have to be chosen based on the VEC and cumulative stressors identified in the Level 2 risk assessment described in this framework. A range of methods and approaches from existing processes already exist at this level, but there remain challenges in finding methods that address multiple stressors and different types of ecological components.

The risk estimations described in Level 1 and 2 assessments provide a relative ranking of risk within the spatial domain chosen. Consequently, the results can only be used to compare risk within the assessment area, and cannot be used to compare risk with areas outside the spatial boundaries. In contrast, Level 3 assessments are likely to estimate absolute risk due to the quantitative nature of these assessments.

3 DISCUSSION

A key goal of this ecological risk assessment framework (ERAF) is to provide a systematic and transparent process to guide the transition from high-level aspirational principles and goals to more tangible and specific objectives, strategies and actions that could be implemented in PNCIMA and MPA initiatives in the Pacific Region. The ERAF does this by identifying and prioritizing the anthropogenic risks to valued ecosystem components. This approach to risk assessment should facilitate the communication of clear and transparent science advice to managers on the ecological risk consequences of anthropogenic stressors on ecosystem components, and identify stressors that may require enhanced management attention.

The framework described in this document meets these objectives by:

1. Categorizing and identifying Valued Ecosystem Components (VECs);
2. Utilizing pathways of effects (PoE) models to elucidate the potential effects of activities and associated stressors to VECs;

3. Developing a risk assessment methodology used to determine single and cumulative risk of harm to VECs;
4. Providing an assessment of uncertainty at different stages in the risk assessment;
5. Allowing for flexible application at different management scales (e.g. Environmental Impact Assessments, MPAs, PNCIMA); and
6. Providing an adaptable approach to allow integration of additional information as it becomes available.

Many different types of ecological risk assessment frameworks (ERAFs) exist to address the risks to ecosystem components resulting from human activities. DFO Pacific Region has built upon approaches already adopted by DFO Nationally and in other Regions, as well as building on international best practices. However, few of the ERAFs from other regions or other countries are able to comprehensively capture all of the components that make up an ecosystem, while addressing the cumulative impacts from multiple stressors and incorporating uncertainty at each stage of the assessment process. For example, several risk assessment frameworks have been developed for habitat assessment (Halpern et al. 2008, 2009; Tallis et al. 2011; Williams et al. 2011), or for species components (Samhouri and Levin 2012), but these frameworks do not consider other valued ecosystem components, such as community properties. Other frameworks have developed semi-quantitative risk assessments for specific activity and stressor types (e.g., fisheries capture: Hobday et al. 2007; Williams et al. 2011; Holt et al. 2012), but do not provide clear guidance on scoring for multiple activities and stressors on different VECs. To address these gaps, the ERAF described in the present document has utilized methodology from several different processes, while also considering improvements upon these methods, to provide a comprehensive ecosystem-based ERAF suitable for PNCIMA and MPAs in the Pacific Region. Developing this risk-based framework has brought forward a number of advancements as captured above, but also highlights several challenges to identifying priorities for EBM as discussed below.

3.1 CATEGORISING AND IDENTIFYING VALUED ECOSYSTEM COMPONENTS (VECS)

Many habitat types, community/assemblage types, and ecosystem properties have not been defined in a comprehensive manner for the PNCIMA, or even for MPAs. Future efforts to provide complete classifications of habitats, communities, and ecosystem properties in the Pacific Region will be critical for addressing these components. These activities should be of a collaborative nature with the full involvement of government departments, non-government organizations, stakeholders, and other interested parties. The current shift towards ecosystem-based science is expected to contribute significantly to the identification of community/assemblage types in the Pacific Region. Even where classifications schemes are available, spatial and temporal data are missing for many VECs. These data gaps result in greater uncertainty when defining VECs and assigning ranking in the qualitative (level 1) and semi-quantitative (level 2) phases of the risk assessment. However, the flexibility of the modular approach allows for both qualitative and quantitative information to be incorporated and updated as warranted.

As mentioned in section 2.2.2 (Level 2 Risk Assessment), the distribution of ecosystem components and stressors in a region does not necessarily conform with spatial boundaries established by management; thus, both the impacts and risks to ecosystem components are likely not fully defined by interactions within such areas. This mismatch means that the ERAF provides a relative assessment of risks to ecosystem components within the area chosen for assessment. Consequently, the results cannot be used to compare risks among areas inside

and outside of the assessment boundaries. Furthermore conditions outside the assessment boundary can affect the interactions within the area being assessed. Those conditions that influence the risk to an ecosystem component are accounted for within the risk calculation, captured in part by the uniqueness and connectivity attributes.

3.2 UTILISING PATHWAYS OF EFFECTS (POE) MODELS TO ELUCIDATE THE POTENTIAL EFFECTS OF ACTIVITIES AND ASSOCIATED STRESSORS TO VECS

PoE models have been identified by DFO as an essential tool for evaluating ecosystem impacts from human activities (DFO, 2011), and are being developed to provide the background information needed for risk analysis processes. Since these models illustrate cause-effect relationships and identify the mechanisms by which stressors ultimately lead to effects in the environment, PoE models can help managers in establishing priorities and focusing resources on identifying, managing and regulating those activities with the greatest potential to produce negative effects on ecosystems. PoE models also provide a way of visualizing these impacts in diagrams, aiding in the communication of this information. However, the nature and extent of many of the activities and associated stressors present in Pacific waters remains unknown. These knowledge gaps can be easily identified through the process of developing PoE models, and will highlight where there is a need for additional research on the impacts of certain stressors.

3.3 DEVELOPING A RISK ASSESSMENT METHODOLOGY TO DETERMINE SINGLE AND CUMULATIVE RISK OF HARM TO VECS

3.3.1 Level 1 Risk Assessment

Risk assessments need to be conducted relatively quickly yet be transparent, integrated, and grounded in science. The goal of the Level 1 risk assessment is to provide a rapid tool for identifying the most significant stressors for each VEC to take into a higher level of risk assessment and is particularly important when dealing with a large number of activities, stressors and VECs. The proposed approach used to filter out these activities is comprehensive, transferable, and able to capture uncertainty.

The advantage of conducting a Level 1 assessment is that many potential risks will be screened out so that only the activities and stressors identified as higher risk are considered in the more intensive and quantitative analyses at Levels 2 and 3. Furthermore, high-risk activities can be rapidly identified, potentially leading to an immediate risk management response. However, the drawback is that multiple stressors with low effects individually but significant cumulative effects could be screened out during a Level 1 assessment. To address this shortcoming, it is recommended that VECs exposed to multiple stressors whose cumulative scores put them in the extreme category should be taken into Level 2 of the risk assessment, even though these VECs may have only low or negligible scores to single stressors.

Other risk assessment approaches used within DFO (e.g., Park et al. 2010; Hardy et al. 2011) and elsewhere (Hobday et al. 2007, 2011; Williams et al. 2011) also screen out the risks of potential harm from those activities that pose negligible or low risk. While this screening is a necessary step for large-scale regions such as PNCIMA, for MPAs and local impact assessments, it may be feasible to skip the largely qualitative Level 1 step and move directly from the scoping stage to the Level 2 risk assessment.

3.3.2 Level 2 Risk Assessment

The goal of the Level 2 risk assessment is to estimate the relative risk of harm posed to a VEC by a particular stressor, as well as an assessment of the cumulative effects on each VEC. While

spatial and temporal data exist for some VECs and stressors, in most cases some or all of these quantitative data are not available. This lack of data results in increased uncertainty when assigning ranking in both the qualitative (Level 1) and semi-quantitative (Level 2) phases of the risk assessment. However, although ranking is required to proceed with a risk assessment, the ERAF is designed to capture this uncertainty in a clear and transparent manner at each step in the process using the scoring in Table 11. VEC-stressor combinations with high uncertainty scores are captured as higher risk in the framework in order to be precautionary. This uncertainty reporting also has value as a gap analysis, highlighting where quantitative data will be needed in order to advance to the quantitative risk models in Level 3. Furthermore, as this risk-based framework is designed to incorporate both qualitative and quantitative information, it is flexible enough to be revised with newer more quantitative information when it becomes available.

The risk of human activities to VECs in this ERAF is a function of the exposure of each VEC to each activity and its associated stressors, and the consequences to each VEC. Exposure to stressors can arise through direct overlap in space and time, such as capture by fisheries, or through more diffuse routes, such as chronic exposure to pollution or via impacts to critical habitat at specific times. Consequence is related to the effects of activities and stressors on VECs, and the ability of VECs to recover from these effects (i.e., through processes such as recruitment and regeneration). Outputs from the model can be useful for understanding the relative risk of human activities and stressors to VECs within a study region and among alternative future scenarios.

Unlike many other frameworks that employ only categorical, qualitative metrics of risk (i.e., high, medium, and low) a Level 2 risk assessment in this Pacific Region ERAF captures quantitative information about exposure using a scoring scheme that reflects percent areal overlap, depth overlap and temporal overlap of stressors and VECs. This approach is more discerning among risks and better captures the pathways by which VECs are exposed to stressors. Furthermore, the framework is designed to incorporate qualitative information when quantitative information is not available, allowing for a flexible yet comparative approach. Without quantitative data on consequence attributes (e.g., acute effects, recovery time), it is challenging to develop quantitative risk assessment models. However, semi-quantitative models capture sensitivity and resilience of a species, habitat or community to stressors and allow for an estimation of risk to be calculated with better accuracy than a purely qualitative approach.

3.3.3 Comparison of Approaches to Calculate Risk

Most existing risk assessment frameworks employ one of two different approaches to the calculation of risk: a multiplicative approach (e.g., Exposure x Consequence) (Fletcher et al. 2005; Park et al. 2010, DFO 2013a); or a graphical approach with risk calculated as Euclidean distance between Exposure and Sensitivity/Consequence (Hobday et al. 2007; Williams et al. 2011; Halpern et al.2009, Tallis et al. 2011; Samhouri and Levin 2012).

While the methods described above each calculate risk and provide relative rankings of risk, they are not consistent in the rank order of their relative risk scores. Appendix E illustrates a comparison of the two methods for the example provided in Park et al. (2010) of the risk of harm to seabirds (aggregation, nesting, feeding and refuge in Placentia Bay Extension) with both results sorted in rank order of risk (high to low – see Table A7 in Appendix E). An important performance measure for risk estimation is that stressors with different characteristics that result in the same consequence should be evaluated as having the same risk. For example, with the multiplicative calculation of risk, a population impact of 20% mortality would occur both with a stressor of sufficient intensity to encounter 40% of the population and upon encountering the species causing mortality in 50% of the encounters, and with a stressor that occurs less

intensely so that it encounters only 20% of the population but upon that encounter, has a 100% mortality rate. In contrast, using Euclidean distance to calculate risk results in different evaluations of risk to the VECs for the same stressor intensities and consequences (~100% vs. 64%).

The ERAF described in this document uses the multiplicative method for risk calculation for the following reasons: (1) it is consistent with the Government of Canada Treasury Board Directive[2] on risk assessment; and (2) using the multiplicative method rather than Euclidean distance provides a greater spread among risk scores, allowing for greater discrimination among rankings (Appendix E).

3.3.4 Cumulative Risk

Cumulative risk of multiple stressors on VECs can be calculated using Levels 1 and 2 of the risk assessment, and is calculated as additive (Equation 2) assuming that additivity provides a reasonable first approximation for estimating cumulative risk. This ERAF also describes how to calculate cumulative effects arising from synergistic, compensatory or masking interactions (Section 2.2.2.2.7). Guidance on estimating effects from these other types of interactions is an improvement on the approaches used in many other frameworks, which only acknowledge additive interactions when estimating cumulative risk. However, since knowledge of effects occurring from these different interactions is limited, they are not addressed in this framework at this time.

It is also important to note that screening out multiple low level stressors during a Level 1 assessment could result in significant cumulative effects being screened out of the assessment before proceeding to Level 2. Care should be taken to incorporate the impacts from these low level stressors in all calculations of cumulative effects.

3.3.5 Ecosystem Risk

In this risk framework we have provided two approaches to estimate risk to ecosystem structure and function, $\mathbf{ERisk}_v$ and $\mathbf{RoleRisk}_R$ (Section 2.2.2.2.8). The former provides a metric for estimating the ecosystem sensitivity to the loss of each VEC, while the latter estimates the potential risk resulting from the loss of a particular ecosystem structure or function across the set of VECs that contribute to that function. At present there is limited information on which ecosystem functions should be considered in assessing ecosystem risk and how different VECs contribute to those functions.

3.3.6 Level 3 – Quantitative Risk Assessment

Level 3 of the risk assessment can only be developed and applied if quantitative data are available because it estimates absolute risk. Like all quantitative models, the accuracy of the results will depend on the amount and quality of the data upon which the model is built. As described above, a range of methods and approaches exist that can be built upon to quantify impacts from multiple stressors, but the data needed to apply these methods is often lacking for many stressors and VECs.

3.4 ASSESSMENT OF UNCERTAINTIES

A recurring challenge with any risk assessment framework is to ensure that uncertainty is addressed. It is critical to capture uncertainty at each step within the process to inform management as to where additional research or data collection can be effectively used to

[2] Framework for Management of Risk (Accessed October 8, 2014)

address gaps. Two approaches are used in the various risk frameworks in Canada and internationally: a) default adjustment upward of the risk estimate to account for uncertainty in the estimate (precautionary); or b) separate reporting of the uncertainty estimate. As described in this paper, uncertainty is recorded as a separate score in a clear and transparent manner at each stage of the process (Table 11). However, a precautionary approach is also taken when assessing risk under high uncertainty, where in the absence of information, evidence or logical argument to the contrary, risk is set as high and the factors in question are moved through the risk assessment framework so as to be captured in the cumulative risk assessment. Thus, the approach taken here is a combination of the approaches used elsewhere.

It is expected that knowledge gaps and data uncertainty will be a challenge as the ERAF is applied in terms of both its structure (e.g., scoring metrics, cumulative risk, assumptions related to the nature of biological effects, the recovery time of ecosystem components, etc.) and data inputs (e.g., lack of spatial/temporal data for some species, habitats, communities). Although modifications to the ERAF will be needed to address these challenges, these modifications cannot be precisely specified in the absence of experience in applying the ERAF.

3.5 ALLOWING FOR FLEXIBLE APPLICATION AT DIFFERENT MANAGEMENT SCALES

This proposed ERAF was developed as a tool that could be employed to assess the risk from existing activities and new activity proposed or introduced in the PNCIMA, individual MPAs, or in other areas of interest in the Pacific Region. In addition, the ERAF can be employed much more broadly to evaluate the mitigation value of certain management responses, such as setting boundaries for fisheries closures, or siting criteria for aquaculture or log handling facilities. It also can be employed each time a new MPA is proposed to determine what form of enhanced management may be needed to address the activities in the area.

The ERAF is discussed in this paper with respect to the PNCIMA, the only large ocean management area (LOMA) in the Pacific Region. However, there are other management areas in the Pacific region that have not been discussed, including fisheries closures and Rockfish Conservation Areas (RCAs). As this framework was developed to be scale independent, its application should be transferable to other management areas at different spatial scales.

3.6 NEXT STEPS – ADAPTING THE FRAMEWORK TO NEW INFORMATION

Although in its current state the proposed ERAF can provide scientific advice for ecosystem-based management, many factors were out of scope and were not incorporated into the framework. The flexible nature of this framework provides an adaptable approach to allow integration of additional information and methodology as they become available. These factors constitute the next steps forward for this process, and some of these key topics/factors are discussed below.

Classification of Habitats and Communities:

The development of methods for classifying benthic habitats, pelagic habitats, and ecological communities in British Columbia is needed before Level 1 or Level 2 analyses can be applied to habitat or community and ecosystem components.
A fine-scale bioregional classification is currently being developed within DFO in conjunction with the MPA Implementation Team (MPAIT) in response to a request from DFO Oceans in order to meet DFO's commitment to design a network of MPAs within Pacific Region. Once completed, the outcomes of this classification may be incorporated into this ERAF.

There is very little guidance at present on how to determine which VECs best capture significant community and ecosystem properties. This lack of guidance stems in part from differing interpretations of communities from very large-scale, ocean basin species assemblages appropriate for the PNCIMA scale, to the small-scale, such as assemblages of a single taxon or small scale habitat associations more relevant for the MPA scale (Hobday et al., 2007). Criteria to determine community and ecosystem properties for areas at different scales in the Pacific region are important for the future application of the ERAF described in this document.

Cumulative risk:

Most risk assessment frameworks calculate cumulative risk using the assumption that the risks attributable to each stressor individually are additive. However, other cumulative interactions among stressors are possible, including synergistic, compensatory and masking, but they are difficult to predict and to incorporate into a risk assessment because knowledge on the effects occurring from these interactions is lacking. This gap in knowledge highlights an opportunity to use this ERAF to guide future research on the interactions among multiple stressors and resulting impacts on VECs. Furthermore, impacts from indirect effects (e.g., loss of species productivity from reduced habitat; risk of harm from loss of key prey species) are not incorporated into the cumulative impact calculation for many VECs. It is desirable to quantify these types of linkages and include them in future iterations of this ERAF.

Indicators and Reference Points:

By providing guidance on the transition from high-level aspirational principles and goals to more tangible and specific objectives, strategies and actions for PNCIMA and MPAs, this ERAF sets the path forward for identifying and selecting indicators for species, habitats, and community and ecosystem properties that are not currently assessed. In particular, the ERAF provides guidelines for setting limits or benchmarks for risk based on productivity, representivity, resilience, and connectivity. However, there is much work remaining before indicators can be selected. Examples of relevant measures are provided in Table 2, but developing the methods and criteria for selecting which measures will be good indicators of ecosystem health is a critical step. Further work also is needed to develop benchmarks and thresholds of risk for multiple components to multiple stressors.

Investigating trade-offs among ecosystem services:

In addition to providing an understanding of the relative risk of human activities and natural stressors to VECs within a study region, outputs from the ERAF can help identify marine areas where human activities may create trade-offs among ecosystem services (i.e., benefits provided to humans) when cumulative effects pose a high enough risk to compromise the structure and function of VECs. While this ERAF has started to examine the risk to ecosystem function through the ***$ERisk_C$*** and ***ESensitivity*** metrics in the Level 2 risk assessment, other socio-economic and cultural valuation methods will need to be used to assess trade-offs that arise under different management scenarios for these multiple activities. One tool that could assist in meeting these objectives is the InVEST toolset developed by the Natural Capital Project to quantify and map the values of multiple environmental services in order to evaluate such trade-offs (Tallis et al. 2011).

4 CONCLUSIONS

The ERAF provides an approach to identify potential ecological risks imposed by multiple activities and stressors on multiple species, habitats and/or ecological communities, and highlights the VECs that may be vulnerable to the cumulative effects of single and multiple stressors. This model is an improvement over traditional assessment approaches that consider

individual issues in isolation, and by taking an ecosystem-based management approach, can communicate a broader view of anthropogenic impacts on ecosystem components. The ERAF can also help prioritize science advisory activities by ranking issues based on ecological risk. In addition, the framework informs adaptive ecosystem-based management by summarizing existing knowledge, information and data on the ecological impacts of anthropogenic activities on ecosystem components. This adaptive framework will allow additional refinement and feedback through peer review, resulting in a useful risk-based approach for application in the Pacific Region and beyond.

5 OTHER CONSIDERATIONS

This ERAF is a science contribution focusing on ecological VECs and is part of a broader iterative process in DFO's ecosystem-based approach to integrated oceans management. This broader process will bring together outputs from the application of the ERAF along with social and economic dimensions to derive objectives, strategies and actions for PNCIMA or MPAs. However, there are other ways to identify VECs that include socio-economic dimensions at the outset including The Conservation Measures Partnership's Open Standards for the Practice of Conservation, the British Columbia Conservation Data Centre (CDC) stress assessment process, and the Natural Capital Project's Integrated Valuation of Environmental Services and Tradeoffs (InVEST) tool.

The proposed framework also can be used to evaluate measures to mitigate risk to VECs from activities and associated stressors. The framework assumes that existing mitigation measures for a VEC (e.g., fishery quota, total allowable catch or TAC) remain in place unchanged and evaluates risk to the VEC on this basis. If the mitigation measure is changed (e.g., increased quota or TAC), then the risk profile of the VEC should be re-evaluated.

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7 LIST OF APPENDICES

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Appendix E:

APPENDIX A. DESCRIPTION OF MARINE PROTECTED AREA (MPA) CONSERVATION OBJECTIVES

Bowie Seamount Marine Protected Area

"*Conserve and protect the unique biodiversity and biological productivity of the area's marine ecosystem, which includes the Bowie, Hodgkins and Davidson seamounts and the surrounding waters, seabed and subsoil*".

Endeavour Hydrothermal Vents Marine Protected Area

"*Ensure that human activities contribute to the conservation, protection and understanding of the natural diversity, productivity and dynamism of the ecosystem and are managed appropriately such that the impacts remain less significant than natural perturbations (e.g. magmatic, volcanic or seismic)*".

Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs (proposed) Marine Protected Area

"*To conserve and protect the biological diversity, structural habitat and ecosystem function of the glass sponge reefs*".

Race Rocks (proposed) Marine Protected Area

"To conserve and protect the biodiversity and ecosystem function of the Race Rocks Marine Protected Area" (Backe et al., 2011)."

APPENDIX B. GUIDANCE FOR QUALITATIVE SCORING OF CONSEQUENCE FOR DIFFERENT SUBCOMPONENTS

(Table A1) species; (Table A2) habitat; (Table A3) community properties

Table A1. Species.

	Score/level					
Subcomponent	**1 Negligible**	**2 Minor**	**3 Moderate**	**4 Major**	**5 Severe**	**6 Intolerable**
Population size	Insignificant change to population size/growth rate (r). Unlikely to be detectable against background variability for this population.	Possible detectable change in population size/growth rate (r) but minimal impact on population size and none on dynamics.	Impacts to the population but long-term recruitment dynamics not adversely damaged.	Significant source of mortality. Affecting recruitment state of populations and/or their capacity to increase.	Likely to cause local extinctions if continued in the longer term.	Local extinctions are imminent/immediate.
Geographic range	No detectable change in geographic range. Unlikely to be detectable against background variability for this population.	Possible detectable change in geographic range but minimal impact on population range and none on dynamics. Change in geographic range up to 5% of original.	Change in geographic range up to 10% of original.	Change in geographic range up to 25% of original.	Change in geographic range up to 50% of original.	Change in geographic range >50% of original.
Genetic structure	No detectable change in genetic structure. Unlikely to be detectable against background variability for this population.	Possible detectable change in genetic structure. Any change in frequence of genotypes, effective population size, or number of spawning units up to 5%.	Detectable change in genetic structure. Any change in frequence of genotypes, effective population size, or number of spawning units up to 10%.	Detectable change in genetic structure. Any change in frequence of genotypes, effective population size, or number of spawning units up to 25%.	Detectable change in genetic structure. Any change in frequence of genotypes, effective population size, or number of spawning units up to 50%.	Detectable change in genetic structure. Any change in frequence of genotypes, effective population size, or number of spawning units>50%.
Age/size/sex structure	No detectable change in age/size/sex structure. Unlikely to be detectable against background variability for this population.	Possible detectable change in age/size/sex structure but minimal impact on population dynamics.	Detectable change in age/size/sex structure. Impact on population dynamics at maximum sustainable level, long-term recruitment dynamics not adversely damaged.	Long-term recruitment dynamics adversely affected. Time to recover to original structure up to 5 generations free from impact.	Long-term recruitment dynamics adversely affected. Time to recover to original structure up to 10 generations free from impact.	Long-term recruitment dynamics adversely affected. Time to recover to original structure up to and greater than 100 generations free from impact.
Reproductive capacity	No detectable change in reproductive capacity. Unlikely to be detectable against background variability for this population.	Possible detectable change in reproductive capacity but minimal impact on population dynamics.	Detectable change in reproductive capacity. Impact on population dynamics at maximum sustainable level, long-term recruitment dynamics not adversely damaged.	Change in reproductive capacity adversely affecting long-term recruitment dynamics. Time to recovery up to 5 generations free from impact.	Change in reproductive capacity adversely affecting long-term recruitment dynamics. Time to recovery up to 10 generations free from impact.	Change in reproductive capacity adversely affecting long-term recruitment dynamics. Time to recovery up to and greater than 100 generations free from impact.

Subcomponent	Score/level 1 Negligible	2 Minor	3 Moderate	4 Major	5 Severe	6 Intolerable
Behaviour/ movement	No detectable change in behaviour/movement. Unlikely to be detectable against background variability for this population. Time taken to recover to pre-disturbed state on the scale of hours.	Possible detectable change in behaviour/movement but minimal impact on population dynamics. Time to return to original behaviour/movement on the scale of days to weeks.	Detectable change in behaviour/movement with the potential for some impact on population dynamics. Time to return to original behaviour/movement on the scale of weeks to months.	Change in behaviour/movement with impacts on population dynamics. Time to return to original behaviour/movement on the scale of months to years.	Change in behaviour/movement with impacts on population dynamics. Time to return to original behaviour/movement on the scale of years to decades.	Change in behaviour/movement. Population does not return to original behaviour/movement.

Table A2. Habitats.

Subcomponent	Score/level 1 Negligible	2 Minor	3 Moderate	4 Major	5 Severe	6 Intolerable
Substrate quality	Reduction in the productivity (similar to the intrinsic rate of increase for species) on the substrate from the activity is unlikely to be detectable. Time taken to recover to pre-disturbed state on the scale of hours	Detectable impact on substrate quality. At small spatial scale time taken to recover to pre-disturbed state on the scale of days to weeks, at large spatial scales, recovery time of hours to days.	More widespread effects on the dynamics of substrate quality but the states are still considered acceptable given the percent area affected, the types of impact occurring and the recovery capacity of the substrate. For impacts on non-fragile subsrates this may be for up to 50% of habitat affected but for more fragile habitats to stay in the category the % area affected must be smaller up to 25%.	The level of reduction of internal dynamics of habitats may be larger than is sensible to ensure that the habitat will not be able to recovery adequately or it will cause strong downstream effects from loss of function. Time to recover from local impact on the scale of monhts to years, at larger spatial scales recovery time of weeks to months.	Severe impact on substrate quality with 50-90% of the habitat affected or removed by the activity which may seriously endanger its long-term survival and result in changes to ecosystem function. Recovery period measured in years to decades.	The dynamics of the entire habitat is in danger of being changed in a major way or >90% of the habitat destroyed.
Water quality	No direct impact on water quality. Impact unlikely to be detectable. Time taken to recover to pre-disturbed state on the scale of hours	Detectable impact on water quality. Time to recover from local impact on the scale of days to weeks, at larger spatial scales, recovery time of hours to days.	Moderate impact on water quality. Time to recover from local impact on the scale of weeks to months, at larger spatial scales, recovery time of days to weeks.	Time to recover from local impact on the scale of months to years, at larger spatial scales recovery time of weeks to months.	Impact on water quality with 50-90% of the habitat affected or removed by the activity which may seriously endanger its long-term survival and result in changes to ecosystem function. Recovery period measured in years to decades.	The dynamics of the entire habitat is in danger of being change in a major way or >90% of the habitat destroyed.

Subcomponent	Score/level 1 Negligible	2 Minor	3 Moderate	4 Major	5 Severe	6 Intolerable
Air quality	No direct impact on air quality. Impact unlikely to be detectable. Time taken to recover to pre-disturbed state on the scale of hours	Detectable impact on air quality. Time to recover from local impact on the scale of days to weeks, at larger spatial scales, recovery time of hours to days.	Detectable impact on air quality. Time to recover from local impact on the scale of weeks to months, at larger spatial scales, recovery time of days to weeks.	Time to recover from local impact on the scale of months to years, at larger spatial scales recovery time of weeks to months.	Impact on air quality with 50-90% of the habitat affected or removed by the activity which may seriously endanger its long-term survival and result in changes to ecosystem function. Recovery period measured in years to decades.	The dynamics of the entire habitat is in danger of being change in a major way or >90% of the habitat destroyed.
Habitat distribution	No direct impact on habitat types or distribution. Impact unlikely to be detectable. Time taken to recover to pre-disturbed state on the scale of hours to days.	Detectable impact on the distribution of habitat types. Time to recover from local impact on the scale of days to weeks, at larger spatial scales, recovery time of days to months	Impact reduces distribution of habitat types. Time to recover from local impact on the scale of weeks to months, at larger spatial scales, recovery time of months to <one year.	The reduction of habitat type areal extent may threaten ability to recover adequately or cause strong downstream effects in habitat distribution and extent. Time to recover from local impact on the scale of > one year to <decadal timeframes.	Impacts on relative abundance and distribution of habitat types resulting in severe changes to ecosystem function. Recovery period likely to be >decadal.	The dynamics of the entire habitat is in danger of being changed in a catastrophic way. The distribution of habitat types has been shifted away from original spatial pattern. If reversible, will require a long-term recovery period, on the scale of decades to centuries.
Habitat structure	No detectable change in the internal dynamics of habitat or populations of species making up the habitat. Time taken to recover to pre-disturbed state on the scale of hours to days.	Detectable impact on habitat structure and function. Time to recover from impact on the scale of days to monhts, regardless of spatial scale.	Impact reduces habitat structure/function For impacts on non-fragile habitat structure, this may be for up to 50% of the habitat affected but for more fragile habitats to stay in this category the % area affected needs to be smaller up to 20%.. Time to recover from local impact on the scale of months to <one year, at larger spatial scales, recovery time of months to <one year.	The level of reduction of internal dynamics of habitat may threaten the ability to recover adequately, or it will cause strong downstream effects from loss of function. For impacts on non-fraglie habitats this may be up to 50% of habitat affected but for mor fragile habitats, to stay in this category the % area affected up to 25%. Time to recover from impact on the scale of > one year to <decadal timeframes.	Impact on habitat function resulting from severe changes to internal dynamics of habitats. Time to recover from impact likely to be > decadal.	The dynamics of the entire habitat is in danger of being changed in a catastrophic way which may not be reversible. Habitat losses occur. Some elements may remain but will require a long-term recovery period, on the scale of decades to centuries.

Table A3. Community/Ecosystem properties.

	Score/level					
Subcomponent	**1 Negligible**	**2 Minor**	**3 Moderate**	**4 Major**	**5 Severe**	**6 Intolerable**
Species composition	Interactions may be occurring which affect the internal dynamics of communities leading to change in species composition not detectable against natural variation.	Impacted species do not play a keystone role - only minor changes in relative abundance of other consituents. Changes of species composition up to 5%.	Detectable changes to the community species composition without a major change in function (no loss of function). Changes of species composition up to 10%.	Major changes to the community species composition (~25%) (involving keystone species) with major change in function. Ecosystem function altered measurably and some function or components are locally missing/declining/increasi ng outside of historical range and/or allowed/facilitated new species to appear. Recovery period measured in years.	Change to ecosystem structure and function. Ecosystem dynamics currently shifting as different species appear or relative abundance is altered in the community. Recovery period measured in years to decades.	Total collapse of ecosystem function. Long-term recovery period required, on the scale of decades to centuries.
Functional group composition	Interactions may be occurring which affect the internal dynamics of communities leading to change in functional group composition not detectable against natural variation.	Minor changes in relative abundance of functional group consituents up to 5%.	Changes in community functional group constituents, up to 10%. Chance of flipping to an alternate state/trophic cascade.	Ecosystem function altered measurably and some functional groups are locally missing/declining/ increasing outside of historical range and/or allowed/facilitated new species to appear. Recovery period measured in months to years.	Ecosystem dynamics currently shifting; different functional groups are missing and new species/groups are appearing. Recovery period measured in years to decades.	Ecosystem function catastrophically altered with total collapse of ecosystem function. Recovery period measured in decades to centuries.
Distribution of the community	Interactions which affect the distribution of communities unlikely to be detectable against natural variation.	Possible detectable change in geographic range of communities but minimal impact on community dynamics. Change in geographic range up to 5% of original.	Detectable change in geographic range of communities with some impact on community dynamics. Change in geographic range up to 10% of original.	Geographic range of communities, ecosystem function altered measurably and some functional groups are locally missing/declining/ increasing outside of historical range. Change in geographic range for up to 25% of the species. Recovery period measured in months to years.	Change in geographic range of communities, ecosystem function altered, and some functional groups are currently missing and new groups are present. Change in geographic range for up to 50% of the species including keystone species. Recovery period measured in years to decades.	Change in geographic range of communities, ecosystem function collapsed. Change in geographic range for >90% of the species including keystone species. Recovery period measured in decades to centuries.

Subcomponent	Score/level 1 Negligible	2 Minor	3 Moderate	4 Major	5 Severe	6 Intolerable
Trophic/size structure	Interactions which affect the internal dynamics unlikely to be detectable against natural variation.	Change in mean trophic level, biomass/number in each size class up to 5%.	Changes in mean trophic level, biomass/number in each size class up to 10%.	Changes in mean trophic level. Ecosystem function altered measurably and some function or components are missing/declining/ increasing outside of historical range and/or allowed/facilitated new species to appear. Recovery period measured in months to years.	Changes in mean trophic level. Ecosystem function severely altered and some function or components are missing and new groups present. Recovery period measured in years to decades.	Ecosystem function catastrophically altered as a result of changes in mean trophic level, total collapse of ecosystem processes. Recovery period measured in decades to centuries.
Bio-geochemical cycles	Interactions which affect bio- and geochemical cycling unlikely to be detectable against natural variation.	Only minor changes in relative abundance of other constituents leading to minimal changes to bio- & geochemical cycling up to 5%	Changes in relative abundance of other constituents leading to minimal changes to bio- & geochemical cycling, up to 10%.	Changes in relative abundance of constituents leading to major changes to bio- & geochemical cycling, up to 25%.	Changes in relative abundance of constituents leading to severe changes to bio- & geochemical cycling. Recovery period measured in years to decades	Ecosystem function catastrophically altered as a result of community changes affecting bio- & geochemical cycling. Recovery period measured in decades to centuries.'

APPENDIX C. LEVEL 2 RISK ASSESSMENT: A HYPOTHETICAL EXAMPLE TO SHOW CALCULATION

Table A4. Level 2 Risk Assessment: A hypothetical example to show calculation.

Key Activity/Stressor	Pexposed			Intensity	**Exposure** $\frac{(\boldsymbol{a} \times \boldsymbol{d} \times \boldsymbol{t} \times \boldsymbol{i})}{1000}$	Acute Change	Chronic Change	
	a	d	t	i		ac	cc	ac+cc
Activity 1/Stressor 1	4.4	3	2	8	0.21	3	2	5
Activity 1/Stressor 3	4	4	4	4	0.26	3	0	3
Activity 2/Stressor 1	3	5	10	10	1.50	1	2	3
Activity 2/Stressor 2	10	10	10	10	10.00	3	3	6
Activity 3/Stressor 1	9	9	9	9	6.56	0	3	3
Activity 3/Stressor 2	10	10	8	10	8.00	1	1	2
Activity 3/Stressor n	10	10	9	10	9.00	2	0	2

Key Activity/Stressor	Recovery											**Consequence**	**Risk**
	Max age (ma)	Max size (ms)	Von Bert growth coeff (vb)	Natural mortality (m)	Fecundity (f)	Breeding strategy (bs)	Recruit-ment pattern (rec)	Age at maturity (am)	Population connectivity (conn)	COSEWIC status (stat)	average of (ma + ms + vb + m + f + bs + rec + am + tl + conn + stat)	(ac + cc) x Recovery	Exposure x Consequence
Activity 1/Stressor 1	-	-	-	3	2	3	3	3	2	-	2.67	13.33	2.82
Activity 1/Stressor 3	1	2	1	2	2	1	1	1	1	-	1.33	4.00	1.02
Activity 2/Stressor 1	3	3	3	3	3	3	3	3	3	3	3.00	9.00	13.50
Activity 2/Stressor 2	-	-	-	3	2	2	2	3	3	-	2.50	15.00	150.00
Activity 3/Stressor 1	-	-	-	2	1	1	1	2	3	3	1.86	5.57	36.55
Activity 3/Stressor 2	-	-	-	3	3	3	2	3	2	2	2.57	5.14	41.14
Activity 3/Stressor n	-	-	-	1	2	2	2	1	1	-	1.50	3.00	27.00
											CRisk =	Σ(Risk)	272.04

APPENDIX D. ANALYTIC HIERARCHY PROCESS FOR ASSIGNING WEIGHTS TO DETERMINE CONTRIBUTION OF VECS TO ECOSYSTEM RISK.

The Analytic Hierarchy Process (Saaty 1990) yields a consistent approximation of the relative priorities associated with divergent decision-making criteria. Establishing the weights involves pair-wise comparisons of the various criteria according to a standard rating scale (Table A5). When the first criterion (a) is compared with the second (b), the importance of (a) relative to (b) is assessed. If they are equally important a weight of 1 is assigned to each criterion. If one is more important than the other, a weight in the range 2 – 9 is assigned to the more important criterion according to the values shown in Supplemental Table A5 below, and the reciprocal of this weight is assigned to the other component.

Table A5. Fundamental Scale for Weighting Relative Importance of Criteria. Taken from Saaty (1990).

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the possible highest order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity *i* has one of the above numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

The trial weights are recorded in a square matrix in which the set of criteria to be compared is arrayed on both axes. As the comparisons are made each pair of weights is entered into the matrix with the weight for each in its row under the column of the other. With n components there are $(n^2 - n)/2$ comparisons to be made. Values on the diagonal (row and column for the same component) are all set to 1.

Typically there is inherent inconsistency in assigning the initial set of trial weights across a set of criteria (for example in the relative weighting of (a) relative to (b), (a) relative to (n) and (b) relative to (n)). However, with the scoring method for assigning trial weights described above, the true relative weights across the set of criteria is given by the right eigenvector of the matrix. Software developed specifically for the AHP reports the priority vector, plus measures that give an indication of the degree of inconsistency in the assignment of the trial weights.

APPENDIX E. COMPARISON OF METHODS: MULTIPLICATIVE VS. EUCLIDEAN DISTANCE

Example calculation of risk of harm to Seabirds (aggregation, nesting, feeding and refuge in Placentia Bay Extension) (Park et al. 2010)

Table A6. Risk of harm calculation using Euclidean distance vs. Multiplicative calculations

- Stressor	Magnitude of Interaction	Sensitivity	Euclidean Distance	Multiplicative Risk
GN	1.1	8.2	8.27	9.02
Hunt	2.2	7.3	7.62	16.06
Oil	6.1	8.7	10.63	53.07
POPs	2.7	4	4.83	10.80
Litter	4.5	5.5	7.11	24.75
HABs	0.8	4	4.08	3.20
		Totals:	42.53	116.90

Table A7. Rank Order of Risk of Harm scores from Highest to Lowest

Stressor	Euclidean Distance	Stressor	Multiplicative Risk	rank order match
Oil	10.63	Oil	53.07	TRUE
GN	8.27	Litter	24.75	FALSE
Hunt	7.62	Hunt	16.06	TRUE
Litter	7.11	POPs	10.80	FALSE
POPs	4.83	GN	9.02	FALSE
HABs	4.08	HABs	3.20	TRUE

8 GLOSSARY AND ACRONYMS

Activity – An action that may impose one or more stressors on the ecosystem being assessed.

BCCDC, British Columbia Conservation Data Centre - source for conservation information on approximately 6000 plants and animals, and over 600 ecological communities (ecosystems) in British Columbia. The online BC Species and Ecosystems Explorer is used to generate lists of provincial species and ecological communities based on a number of criteria options, including conservation or legal status, and spatial distribution (http://www.env.gov.bc.ca/cdc/).

Biodiversity - The full range of variety and variability within and among living organisms and the ecological complexes in which they occur. Encompasses diversity at the ecosystem, community, species, and genetic levels and the interaction of these components" (DFO). Biodiversity includes the number of species and their abundance (species richness is the number of species, whereas species abundance is a measure of how common the species is in that environment).

Biogenic habitat - habitat created by a living organism, e.g. coral, sponge, kelp

Bycatch - see 'Non-target species'

CEAA, Canadian Environment Assessment Agency – Provide environmental assessments that contribute to informed decision making, in support of sustainable development. The Agency plays a leadership role in the review of major projects assessed as comprehensive studies and those referred to review panels.

Community – a group of actually or potentially interacting species living in the same place. A community is bound together by the network of influences that species have on one another.

COSEWIC - The Committee on the Status of Endangered Wildlife in Canada - a committee of experts that assesses and designates which wildlife species are in some danger of disappearing from Canada.

Cumulative Impacts - The combined total of incremental effects that multiple human activities through space and time can have on an environment.

DFO – The federal Department of Fisheries and Oceans in Canada.

Ecosystem – A dynamic complex of plant, animal, and microorganism communities, climatic factors and physiography, all influenced by natural disturbance events and interacting as a functional unit.

EBSAs - (Ecologically and Biologically Significant Areas) are areas worthy of enhanced management or risk aversion. An area is identified as an EBSA if it ranks highly on one or more of three dimensions (Uniqueness, Aggregation and Fitness Consequences), and can be weighted by two other dimensions (Naturalness and Resilience), agreed upon at a national DFO workshop

Ecosystem-based Management (EBM) - An integrated approach to making decisions about ocean-based activities, which considers the environmental impact of an activity on the whole ecosystem, not only the specific resource targeted. Ecosystem-based management should also take into account the cumulative impact of all human activities on the ecosystem within that area.

Ecosystem components – Components selected through a defined process to represent the ecosystem of interest

Ecosystem component groups - Used to represent the ecosystem, three categories are considered in this process: Species, Habitats and Community/Ecosystem properties.

Ecosystem function – the physical, chemical, and biological processes or attributes that contribute to the self-maintenance of the ecosystem, for example nutrient cycling.

Endangered – Species facing imminent extirpation or extinction.

Endemic species – A species unique to a defined geographic area and only existing in that location.

Epifauna - Benthic animals that live on the surface of a substrate, such as rocks, pilings, marine vegetation, or the sea or lake floor itself. Epifauna may attach themselves to such surfaces or range freely over them, as by crawling or swimming.

Fitness - the ability to survive and reproduce

Forage species - Marine taxa that serve as an important source of food for marine predators, including finfish and invertebrates, seabirds and marine mammals. Examples include zooplankton, kelps and seagrasses, marine invertebrates, small schooling fish, herring, sand lance, eulachon, harbour seals.

Functional groups – a way to group organisms in an ecosystem by their functional role, usually mode of feeding, for example grazers, filter feeders, deposit feeders, and trophic level.

Habitat - Habitats can be defined in many ways, but one of the simplest is the "place where an organism lives". Habitats not only represent the fundamental ecological unit in which species interact, but it is the matrix that supports an essential range of ecological processes. The loss or impairment of habitat integrity can result in direct impacts to species, communities and ecosystem structure and function (Bax et al.1999; Bax & Williams 2001).

Highly influential species - Species that, in food webs, have high interaction strengths. They are connected to a large number of other species given the overall richness of the food web, and may influence population dynamics of other species.

Infauna - Benthic animals that live in the substrate of a body of water, especially in a soft sea bottom. Infauna usually construct tubes or burrows and are commonly found in deeper and subtidal waters. Examples include clams, tubeworms, and burrowing crabs.

IAs - (Important Areas) are areas identified through a variety of processes as critical for the completion of life history process (e.g., spawning, nesting, rearing) of a species.

IM, Integrated Management - Integrated management: A commitment to planning and managing human activities in a comprehensive manner while considering all factors necessary for the conservation and sustainable use of marine resources and the shared use of ocean spaces (Canada's Oceans Strategy, 2002)

IUCN, International Union for Conservation of Nature – the IUCN Red List of Threatened Species provides taxonomic, conservation status and distribution information on plants and animals that have been globally evaluated using the IUCN Red List Categories and Criteria. The main purpose is to catalogue and highlight those plants and animals that are facing a higher risk of global extinction (i.e. those listed as Critically Endangered, Endangered and Vulnerable). Also included is information on taxa that cannot be evaluated because of insufficient information (i.e., are Data Deficient); and on plants and animals that are either close to meeting the threatened thresholds or that would be threatened were it not for an ongoing taxon-specific conservation programme (i.e., are Near Threatened). http://www.iucnredlist.org/

Keystone species – A species that exerts control on the abundance of others by altering community or habitat structure, usually through predation or grazing, and usually to much greater extent than might be surmised from its abundance (Pitcher et al., 2007).

Non-target species - Species affected by a fishery or fisheries and comprising:

a. Bycatch (the sum of the retained catch of non-targeted species [Incidental catch'] and that portion of the catch returned to the sea as a result of economic, legal, or personal considerations ['Discarded catch'])

b. Unobserved Fishing Mortality - Mortality imposed on a species by the encounter with fishing gear that does not result in capture (e.g., seabirds for sablefish trap fishery at Bowie Seamount)

c. Unobserved Fishery Mortality - Death resulting from fishing that cannot be documented from observations of the on-board catch (e.g., deaths resulting from fish passing through webbing, freeing themselves from hooks, ghost fishing, etc.) (Alverson et al. 1994)

Nutrient importing/exporting species - Species which play a crucial role in maintaining ecosystem structure and function through the transfer of energy or nutrients that would otherwise be limiting to an ecosystem, into that system from sources outside the spatial boundaries of the ecosystem.

Pathways of Effects (PoE) - A PoE model is a representation of cause-and-effect relationships between human activities, their associated sources of effects (stressors or pressures), and their impact on specific ecosystem components. These models illustrate cause-effect relationships and identify the mechanisms by which stressors ultimately lead to effects in the environment.

Population - Group of individuals of the same species that live in the same place and that (potentially) interact with one another to influence each other's reproductive success.

Productivity - A measure of a habitat's current yield of biological material (DFO) - Species richness and abundance have been hypothesized to increase with ecosystem productivity.

PSA (Productivity-Susceptibility Analysis) - A risk assessment that uses susceptibility to capture the extent of the impact and productivity to capture the rate at which the unit can recover after the stressor occurs (a risk analysis based on lower levels of empirical data).

Resilience – Ecological resilience is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks, i.e., without changing self-organized processes and structures. Resilience can also be defined as the ability of an ecosystem to return to an equilibrium or steady-state following a perturbation.

Risk (ecological risk) – A measure of the probability that adverse ecological effects may occur, or are occurring, as a result of the exposure to one or more stressors.

> ***Risk – (specific for this process)*** - the likelihood that a Valued Ecosystem Component will experience unacceptable adverse consequences due to exposure to one or more identified stressors

SARA, Species at Risk Act - The purposes of the SARA are to prevent wildlife species in Canada from disappearing, to provide for the recovery of wildlife species that are extirpated (no longer exist in the wild in Canada), endangered, or threatened as a result of human activity, and to manage species of special concern to prevent them from becoming endangered or threatened.

Species richness - often given simply as the number of species, more commonly used is an index which incorporates the total number of individuals.

Species at Risk - An extirpated, endangered or threatened species or a species of special concern (formerly called vulnerable) (BCCDC)

Species of special concern – Species particularly sensitive to human activities or natural events but not necessarily endangered or threatened [as used by COSEWIC - A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.] Special Concern was formerly referred to as Vulnerable (BCCDC).

Stressor – Any physical, chemical, or biological means that, at some given level of intensity, has the potential to negatively affect an ecosystem

Susceptibility - Susceptibility is composed of three aspects: availability, encounterability and selectivity

Taxonomic distinctness – a univariate biodiversity index which, in its simplest form, calculates the average 'distance' between all pairs of species in a community sample, where this distance is defined as the path length through a standard Linnaean or phylogenetic tree connecting these species. It attempts to capture phylogenetic diversity rather than simple richness of species and is more closely linked to functional diversity; it is robust to variation in sampling effort and there exists a statistical framework for assessing its departure from 'expectation'; in its simplest form it utilises only simple species lists (presence/absence data) (Clarke and Warwick, 1999)

Target species - Species targeted by a fishery in the area of interest, information from the literature and DFO sources.

Vulnerable species - Particularly sensitive to human activities or natural events. [As used by NatureServe - Vulnerable due to a restricted range, relatively few populations, recent and widespread declines, or other factors making it vulnerable to extirpation.] (BCCDC).

Valued Ecosystem Component (VEC) – Ecosystem components deemed to have particular value due to fulfilling specific criteria or roles. Though VECs can be ecological, socioeconomic, or cultural in nature, the focus in this process is only on those of ecological significance, which include biological, oceanographic and physical components important to the ecosystem.